US005406693A

United States Patent [19]

Egashira et al.

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[45] **Date of Patent:** Apr. 18, 1995

[54] **METHOD OF MANUFACTURING A HELICAL ANTENNA FOR SATELLITE COMMUNICATION**

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[73] Assignee: **Harada Kogyo Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **87,168**

[22] Filed: **Jul. 2, 1993**

[51] **Int. Cl.**^{6} **H01P 11/00**

[52] **U.S. Cl.** **29/600**; 343/895

[58] **Field of Search** 29/600; 343/895

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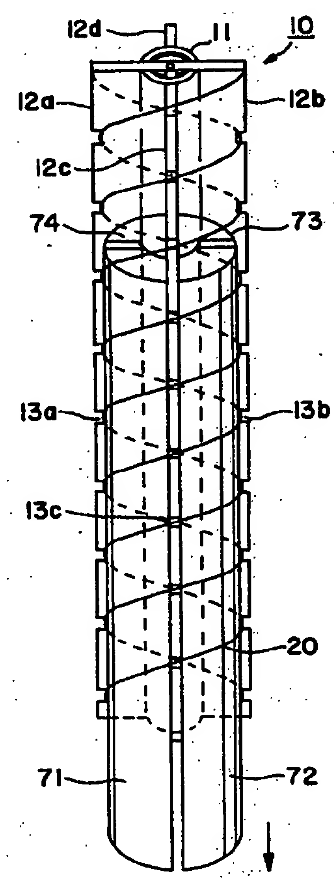
Primary Examiner—Carl J. Arbes
Attorney, Agent, or Firm—Koda and Androlia

[57] **ABSTRACT**

[Object] To provide a method of manufacturing a helical antenna for satellite communications which has no local bent, etc. in the completed helical coil even though the conductor wire used is of an extremely pliable material, so that a high-quality helical antenna for use in satellite communications is obtained.

[Structure] A winding frame **10** in which supporting elements **12** are projected in the form of a cross from the outer circumferential surface of a rod-form base **11** is first obtained. Wedge members **71** through **74**, each of which having a configuration of a cylindrical body divided into four sections along its axis, are installed between the supporting elements **12**. Then, with the cylindrical surfaces of the wedge members **71** through **74** being used as a winding guide, a conductor wire is wound in helical form through conductor wire installation grooves **13** formed on the edges of the supporting elements **12**. Thus, a helical coil **20** is formed. Afterward, the wedge members are removed from the winding frame **10**; as a result, an antenna element of a helical antenna suitable for satellite communication is obtained.

1 Claim, 6 Drawing Sheets



04/13/2001, EAST Version: 1.02.0008

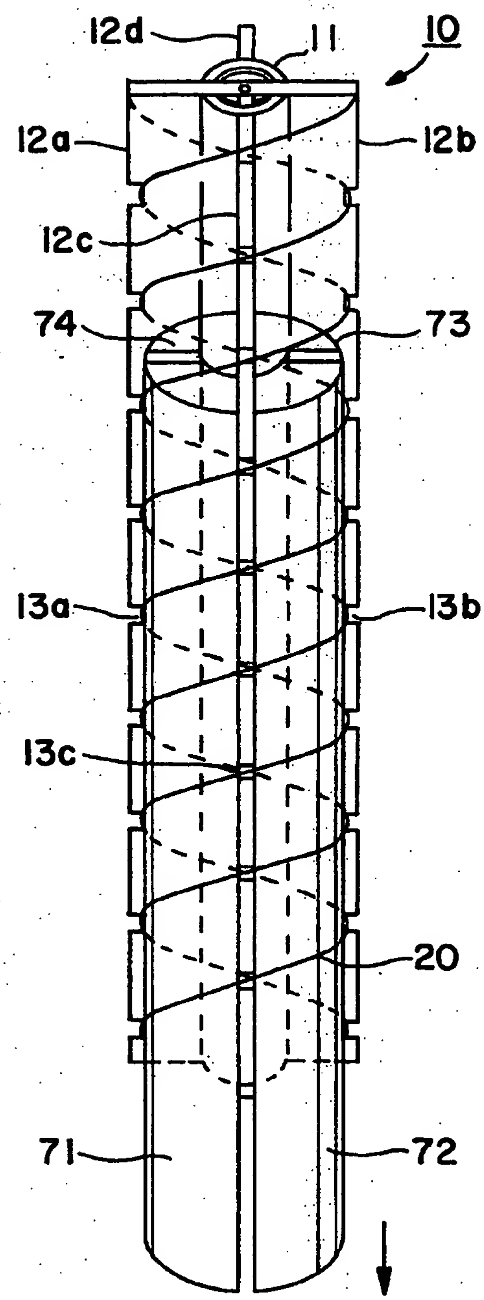


FIG. 1

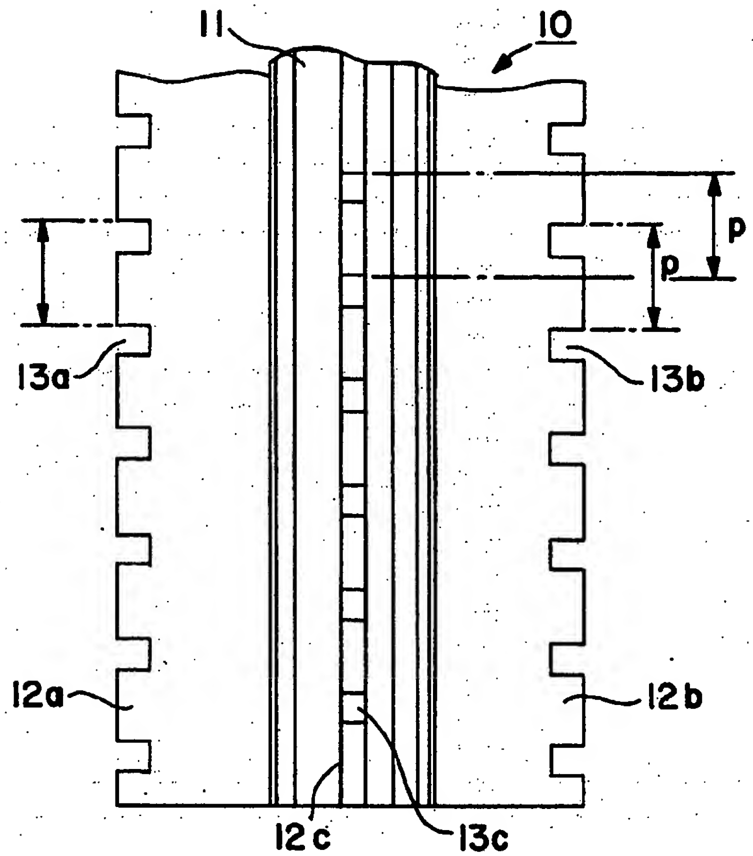

11
10
p
p
13a
13b
12a
12b
12c
13c

FIG. 2(a)

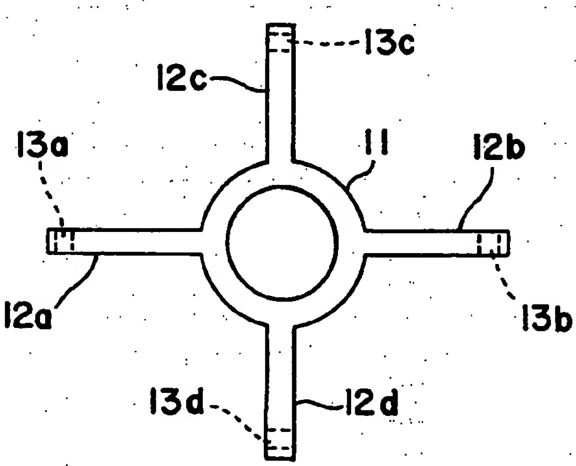

13c
12c
13a
11
12b
12a
13b
13d
12d

FIG. 2(b)

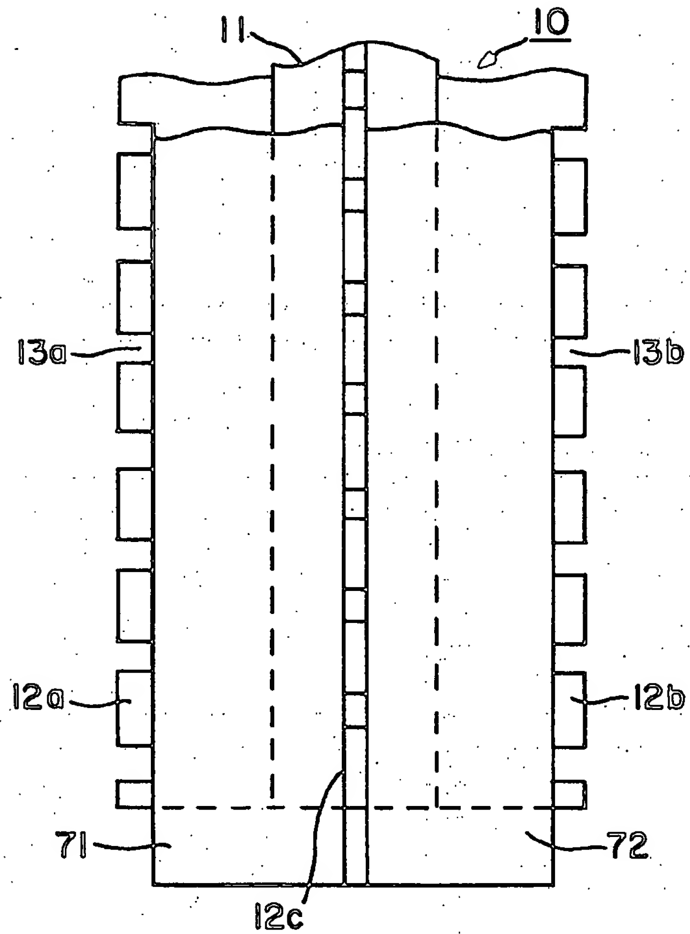


FIG. 3(a)

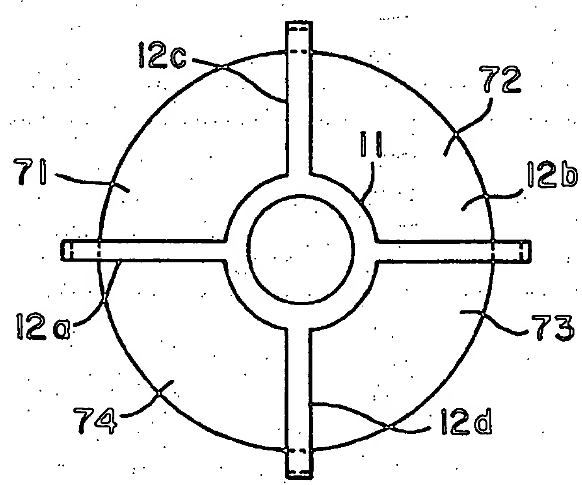


FIG. 3(b)

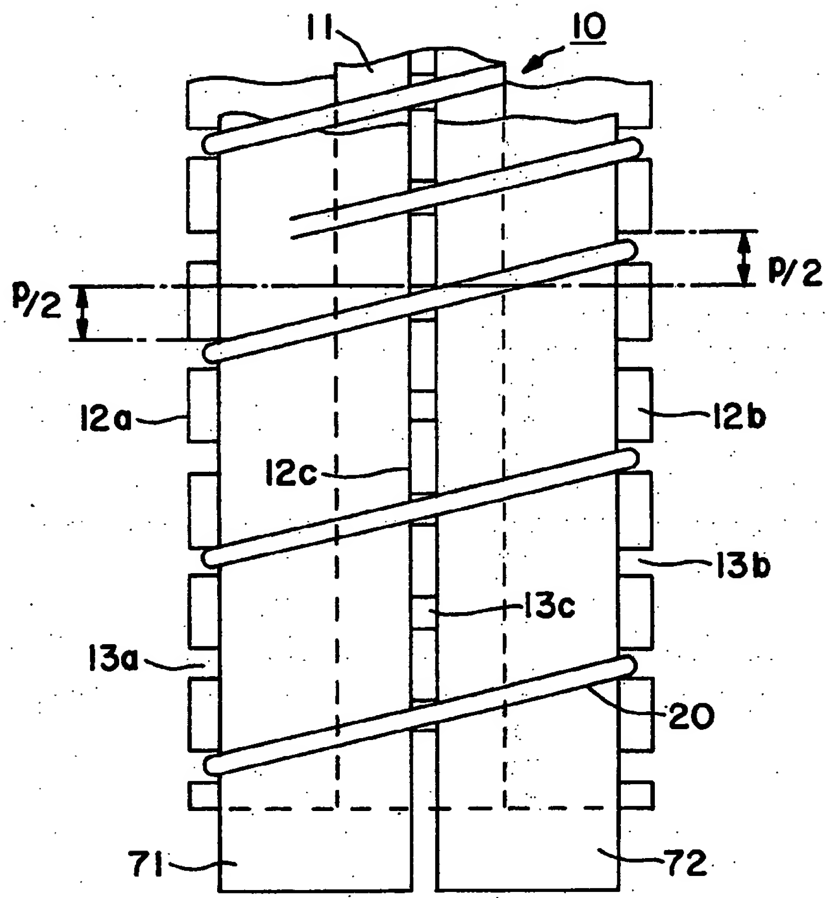

11
10
p/2
p/2
12a
12b
12c
13b
13c
13a
20
71
72

FIG. 4(a)

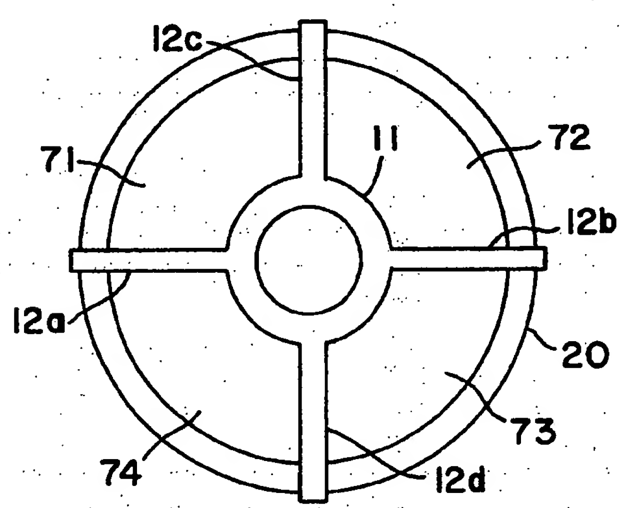

12c
11
72
71
12b
12a
20
73
74
12d

FIG. 4(b)

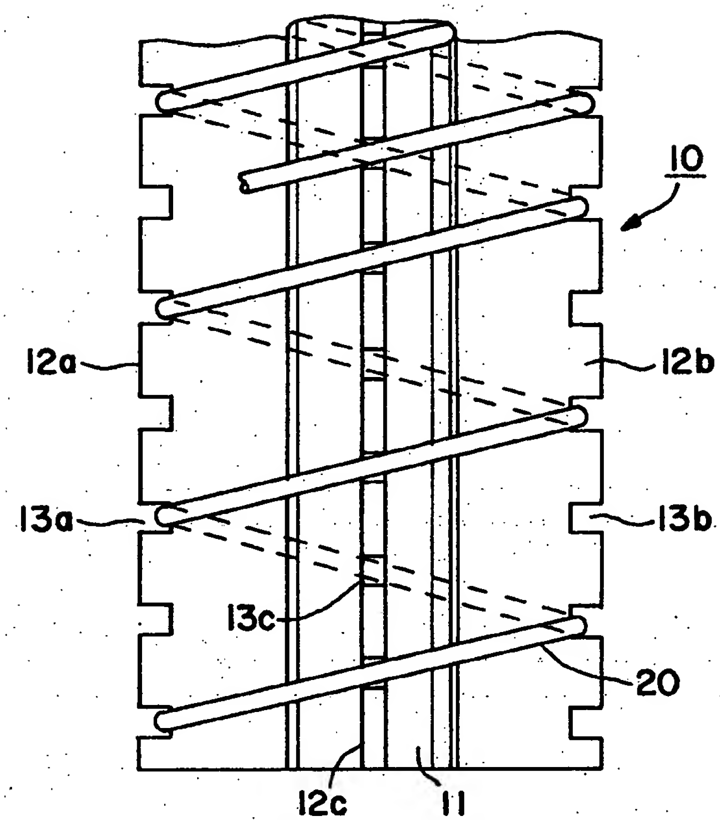


FIG. 5(a)

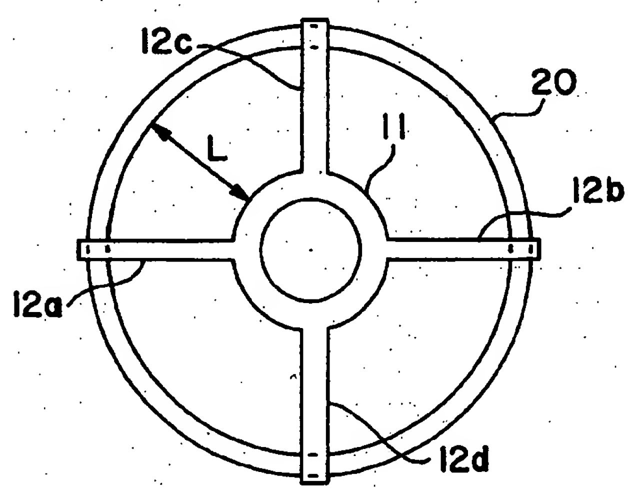


FIG. 5(b)

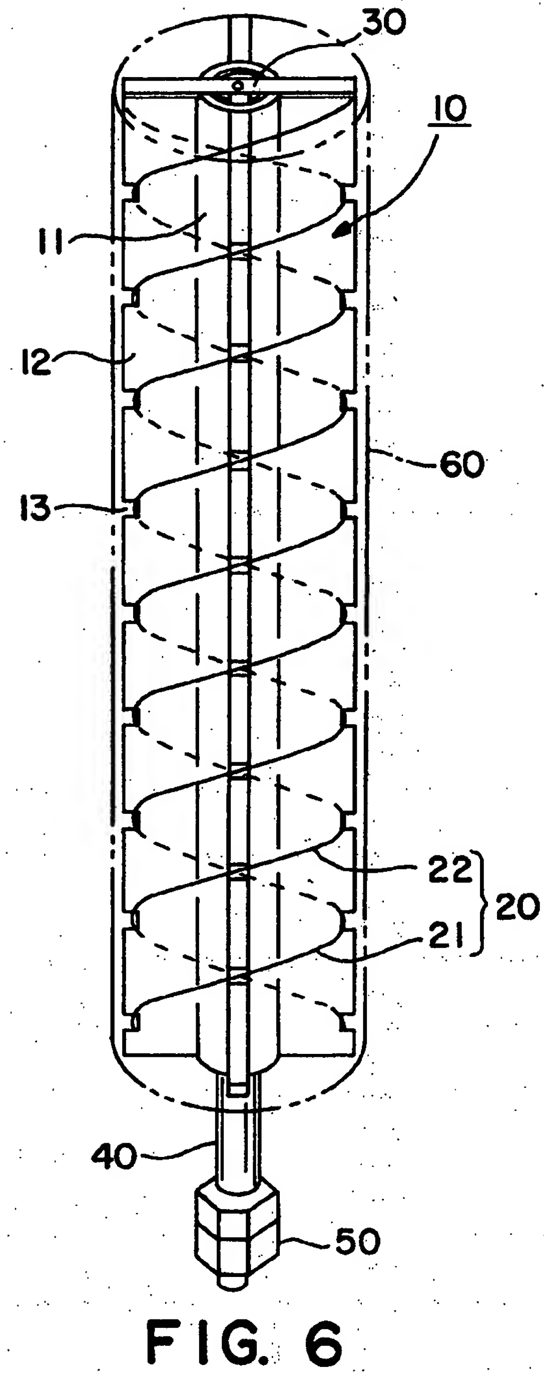


FIG. 6

METHOD OF MANUFACTURING A HELICAL ANTENNA FOR SATELLITE COMMUNICATION

The present invention relates to a method of manufacturing a helical antenna used in satellite communications which is obtained by winding a conductor wire into helical form around a cylindrical or columnar shape winding frame.

PRIOR ART

One type of conventional helical antenna for satellite communications is obtained by coiling a conductive wire in a spiral groove which is formed in the outside circumferential surface of a relatively large diameter cylindrical winding frame that is made of a dielectric material.

Japanese Utility Model Application Laid-Open (Kokai) No. 3-32811 discloses another type of helical antenna. In this antenna, a multiple number of rectangular ribs are installed radially around the outer circumferential surface of a cylinder. Then, through-holes which are used for inserting a helical element are formed in the edge portions of the ribs, and a helical element which has been preformed into a shape of a coil (that is, a helical coil) is successively forced into the through-holes from its end.

In the antennas described first in the above, the winding pitch of the helical coil is determined by the positions of the spiral groove formed in the outside circumferential surface of the winding frame. Accordingly, helical coils of different pitches cannot be produced by the winding frame of the same (or single) model. Naturally, it is also impossible to obtain helical coils in different winding directions. Furthermore, since the helical coil is embedded in the winding frame that is made of a dielectric material of a prescribed dielectric constant, the dielectric constant of the dielectric material considerably affects the antenna characteristics.

In the antenna described secondly in the above, the helical element (or the helical coil) which has been formed into a coil shape beforehand is installed by being forced into, from its end, the through-holes formed in the edge portions of the rectangular ribs. As a result, it needs many winding processes, and the cost of the antenna tends to be high.

In order to eliminate the problems seen in the antennas described above, the inventors of the present application previously proposed a new helical antenna. This antenna includes a winding frame that is obtained from a rod-form base of a cylindrical or columnar shape and first to fourth supporting members each having a rectangular plate shape and being projected radially from four points of the outer circumferential surface of the rod-form base so that the supporting elements are respectively oriented on two planes which include the central axis of the rod-form base and intersect each other perpendicularly. In this antenna, the first and second grooves (used for conductor wire installation) are formed at a prescribed pitch in symmetrical positions in the respective outside edge portions of the first and second supporting elements, and the first and second supporting elements are provided so as to face each other in angular positions that differ by 180 degrees. The third and fourth grooves (used for conductor wire installation) are formed at a prescribed pitch which is shifted by ½ pitch from the pitch formed on the first and second grooves. The grooves are in symmetrical positions in the respective outside edge portions of the third and fourth supporting elements which face each other in angular positions that differ by 180 degrees and are shifted by 90 degrees from the angular positions of the first and second supporting elements.

According to the helical antenna as proposed above, helical coils with different winding directions, pitches and configurations can be obtained using the winding frames of the same model. In addition, it has a number of other merits. For example, the dielectric material for the winding frame has almost no effect on the antenna characteristics, the working characteristics of the winding operation are conspicuously improved so that the required winding work is greatly reduced, and the antenna can be manufactured at a low cost.

PROBLEMS THE PRESENT INVENTION ATTEMPTS TO SOLVE

However, the following problem remains unsolved in the helical antenna described above. More specifically, since the conductor wire is wound in grooves formed in the supporting elements which are assembled in a cross shape, bent portions, etc. tend to occur in the completed coil when the material of the conductor wire is pliable. This may lead to a quality drop of the antenna.

SUMMARY OF THE INVENTION

The present invention was made in light of the facts described above. The object of the present invention is to provide a method of manufacturing a helical antenna for satellite communications which can easily produce a high-quality helical antenna that is free of any local bent portions, etc. in the completed helical coil even when the conductor wire is made of an extremely pliable material.

In order to achieve the object, the following steps are adopted in the present invention. In the first step, a winding frame is obtained. The winding frame includes four supporting elements projected in the form of a cross from the outer circumferential surface of a rod-form base that is of a cylindrical or columnar shape. Each supporting element is shaped in a rectangular plate and is provided with grooves on the outer edge portion at a prescribed pitch so as to be used for installing a conductor wire therein. In the second step, wedge members are installed coaxially with the rod-form base so that they are between the adjacent supporting elements of the winding frame obtained by the first step. Each wedge member is obtained by dividing a cylindrical body into four sections along two planes which include the central axis of the cylindrical body and intersect each other perpendicularly. In the third step, a helical coil is obtained by winding a conductor wire in a helical configuration through the conductor wire installation grooves of the supporting elements which are located between the respective wedge members. In this winding step, the cylindrical surfaces of the wedge members are used as a winding guide. In the last and fourth step, the wedge members are removed from their locations which are between the helical coil and the winding frame after the helical coil has been formed in the third step.

As a result of the method described above, the following effects are obtained. During the formation of the helical coil, the conductor wire is wound in a helical form with the cylindrical surfaces of the wedge members used as a winding guide surface. Accordingly, the conductor wire is wound as if it is wound on the surface

of a single cylindrical body. Thus, even if the material of the conductor wire is extremely pliable, the conductor wire is wound while being kept in an annular shape due to the cylindrical surfaces of the wedge members. Accordingly, an accurate cylindrical coil is obtained. Furthermore, external force that might be applied to the conductor wire during the formation of the helical coil will not cause any danger of the conductor wire being bent or broken. This is because the conductor wire is stably supported by the cylindrical surfaces of the wedge members.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a helical antenna for satellite communication obtained by one embodiment of the manufacturing method of the present invention;

FIGS. 2(*a*) and (*b*) are a front view and an end view which illustrate the first helical antenna manufacturing process in the embodiment; FIGS. 3(*a*) and (*b*) are a front view and an end view which illustrate the second helical antenna manufacturing process in the embodiment;

FIGS. 4(*a*) and (*b*) are a front view and an end view which illustrate the third helical antenna manufacturing process in the embodiment;

FIGS. 5(*a*) and (*b*) are a front view and an end view which illustrate the fourth helical antenna manufacturing process in the embodiment; and

FIG. 6 is a perspective view of the external appearance of a completed helical antenna for satellite communications according to the embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a perspective view of one embodiment of the method of the present invention for manufacturing a helical antenna for satellite communications (FIG. 1 shows the removal of the wedge members being initiated). FIGS. 2(*a*) and 2(*b*) through FIGS. 5(*a*) and 5(*b*) illustrate the manufacturing steps of the helical antenna in the embodiment. In each FIG., (*a*) is a front view and (*b*) is an end view.

As shown in FIG. 1, a winding frame **10** comprises four supporting elements **12*a*** to **12*d***. These supporting elements **12*a*** to **12*d*** are projected from the outer circumferential surface of a rod-form base **11** so as to make a cross shape (when viewed from above). Four wedge members **71** to **74** are installed between the supporting elements **12*a*** through **12*d***. Each wedge member has a configuration of a cylindrical body divided into four sections along the axis of the cylindrical body. Using the cylindrical surfaces of the wedge members **71** to **74** as a winding guide, a conductor wire is wound in a helical shape by being guided into conductor wire installation grooves **13*a*** to **13*d*** which are formed on the outer edge portions of the supporting elements **12*a*** to **12*d***. Thus, a helical coil **20** is formed from the wound conductor wire. Afterward, the wedge members **71** to **74** are moved in the direction of the arrow and then removed from the winding frame **10** or from the area between the helical coil and the supporting elements. Thus, an antenna element of a helical antenna for satellite communications is obtained. In order to facilitate the removal of the wedge members, each one of the wedge members **71** to **74** has an appropriate taper portion in the axial direction.

The steps of manufacture of the helical antenna for satellite communications will be described below with reference to FIGS. 2(*a*) and 2(*b*) through 5(*a*) and 5(*b*).

In the first process, as shown in FIGS. 2(*a*) and 2(*b*), a winding frame **10** is prepared. The winding frame **10** includes first through fourth supporting elements **12*a*** through **12*d***. Each of the supporting elements is of a rectangular plate shape. These supporting elements are assembled so that they project from the outer circumferential surface of a cylindrical rod-form base **11** so that the supporting elements are arranged in a cross shape when viewed from above.

The first through fourth supporting elements **12*a*** through **12*d*** project radially (in the form of a cross) from four locations of the outer circumferential surface of the rod-form base **11**. Thus, the supporting elements **12*a*** through **12*d*** are respectively oriented on two planes which include the axis of the rod-form base **11** and intersect each other perpendicularly. The first and second conductor wire installation grooves **13*a*** and **13*b*** are formed at a prescribed pitch P in symmetrical positions in the respective outside edge portions of the first and second supporting elements **12*a*** and **12*b*** which are installed so as to face each other in angular positions that differ by 180 degrees. The third and fourth conductor wire installation grooves **13*c*** and **13*d*** are formed at a prescribed pitch P and at positions which are shifted by ½ pitch from the pitch P of the first and second grooves **13*a*** and **13*b*** in symmetrical positions in the respective outside edge portions of the third and fourth supporting elements **12*c*** and **12*d***. The third and fourth supporting elements face each other in angular positions that differ by 180 degrees from each other and shifted by 90 degrees from the positions of the first and second supporting elements **12*a*** and **12*b***.

In the second process, as shown in FIGS. 3(*a*) and 3(*b*), wedge members **71** through **74** are installed coaxially with the base **11** body so that they are between adjacent supporting elements **12*a*–12*c***, **12*c*–12*b***, **12*b*–12*d***, **12*d*–12*a*** of the winding frame **10** that is obtained in the first process. Each wedge member has a configuration obtained by dividing a cylindrical body into four sections along two (imaginary) planes which include the center axis of such a cylindrical body and intersect each other perpendicularly.

In the third process, as shown in FIGS. 4(*a*) and 4(*b*), a conductor wire is wound in helical form in such a manner that the conductor wire is guided into the conductor wire installation grooves **13*a*** through **13*d*** of the supporting elements **12*a*** through **12*d*** which are located between the wedge members **71** through **74**. In this winding process, the cylindrical surfaces of the wedge members **71** through **74** are used as a winding guide. The helical coil **20** is thus obtained.

The conductor wire installation grooves **13*a*** through **13*d*** on the outer edge portions of the supporting elements **12*a*** through **12*d*** are formed with a successive shift of ½ pitch at a time between adjacent supporting elements **12*a*–12*c***, **12*c*–12*b***, **12*b*–12*d***, **12*d*–12*a***, regardless of the direction of right-hand rotation or left-hand rotation about the axis. In other words, the grooves **13*a*** through **13*d*** correspond to the helical shape of the helical coil **20**. Accordingly, the winding of the helical coil **20** may be in either the right-hand direction or the left-hand direction. In other words, the coil **20** may be a right-handed twinging coil **20** as shown in FIG. 4 or a left-handed twinging coil (not shown in the FIGS.). Thus, helical coils of different winding directions may

be formed as desired using the same (or single) winding frame 10.

Which conductor wire installation grooves 13*a* should be used in the wire winding process may be chosen in accordance with the intended purpose. In other words, the winding pitch, etc. varies depending upon the selection of the grooves used in the winding of the conductor wire. Thus, the helical coils 20 are obtained in different pitches (for example, 2P, 3P, . . .) or in different configurations (for example, a mixture of 1P and 2P, etc.) using the same or single winding frame 10.

In the fourth process, as shown in FIGS. 5(*a*) and 5(*b*), the wedge members 71 through 74 are removed from winding frame or from the area between the helical coil 20 and the supporting elements after the helical coil 20 has been completed in the third process.

When the wedge members 71 through 74 have been removed, as shown in FIG. 5(*b*), the helical coil 20 is supported by the outside edge portions of the supporting elements 12*a* through 12*d*. Thus, the coil 20 is maintained at a prescribed distance L from the outside circumferential surface of the rod-form base 11. Accordingly, even if the dielectric material having a large dielectric constant is used for the rod-form base 11, the effect of this dielectric material on the antenna characteristics can almost completely be eliminated.

FIG. 6 is a perspective view of the external appearance of a completed helical antenna obtained via the first through fourth processes. As shown in FIG. 6, the conductor wire is wound in helical form around the winding frame 10, to make the helical coil 20. This helical coil 20 consists of first and second coils 21 and 22, each of which being wound a prescribed number of turns around a feeding point 30. The feeding point 30 is connected to the tip end of a coaxial cable 40 that passes through the rod-form base 11 of the winding frame 10. The base end of the coaxial cable 40 is extended from the bottom of the winding frame 10, and a coaxial cable connector 50 is connected to this extended base end. In use, the helical antenna is covered by a cover 60 that is shown by a one-dot chain line in FIG. 6.

The embodiment described above offers the following operating merits. First, during the formation of the helical coil 20, the conductor wire is wound in a helical form with the cylindrical surfaces of the wedge members 71 through 74 used as a winding guide. Accordingly, the conductor wire is wound as if the winding is performed on the surface of a cylindrical body. Thus, even if the material of the conductor wire used is, for example, extremely pliable, the conductor wire can be wound in an annular shape because of the cylindrical surfaces of the wedge members 71 through 74. Thus, an accurate cylindrical coil can easily be obtained. Furthermore, an external force applied to the conductor wire during the formation of the helical coil 20 does not affect the coil, and the conductor wire is not bent or broken, since the wire is stably supported by the cylindrical surfaces of the wedge members 71 through 74. Thus, the quality of the completed helical coil 20 can be conspicuously high.

The present invention is not limited to the embodiments above. The winding frame 10, for example, can consist of a multiple number of segment frames that are obtained by dividing a cylindrical frame into a multiple number of sections along the axis, and these segment frames are connected to each other. Furthermore, the rod-form base 11 and the supporting elements 12*a* through 12*d* can be separate members which are freely connectable. In addition, handles can be installed on the wedge members 71 through 74 in order to facilitate the removal of the wedge members. It goes without saying that various other modifications are available within the spirit of the present invention.

According to the method of the present invention for manufacturing a helical antenna, a winding frame is first obtained so that supporting elements are projected in the form of a cross from the outside circumference of a rod-form base. Next, wedge members, which have the configuration of a cylindrical body divided into four sections along its axial center, are installed between the supporting elements, and a conductor wire(s) is wound in helical form through the conductor wire installation grooves formed in the supporting elements. This winding of the conductor wire(s) is performed with the cylindrical surfaces of the wedge members being used as a guide. A helical coil is thus obtained. Afterward, the wedge members are removed from the winding frame. As a result, an antenna element of a helical antenna for use in satellite communications is obtained. Thus, because of the effect of the wedge members, the method for manufacturing a helical antenna of the present invention can provide a helical antenna which has no local bent, etc. that might occur in the completed helical coil even though the material of the conductor wire used is an extremely pliable. Thus, with the method of the present invention, a high-quality helical antenna for use in satellite communications can be obtained.

We claim:

1. A method of manufacturing a helical antenna for satellite communication comprising:

obtaining a winding frame, said winding frame being obtained via four supporting elements projecting in a cross shape from an outer circumferential surface of a cylindrical base, each one of said four supporting elements being of a rectangular plate shape and being provided with conductor wire grooves at a prescribed pitch formed on an outer edge of said supporting element;

installing wedge members between adjacent supporting elements of said winding frame coaxial with said cylindrical base, each one of said wedge members having a configuration formed by dividing a cylindrical body having an axial taper into four sections along two planes which include a center axis of said cylindrical base and intersect each other perpendicularly;

winding a conductor wire in a helical configuration through said conductor wire grooves of said four supporting elements which are located between said wedge members cylindrical surfaces of said wedge members being used as a winding guide; and

removing said wedge members from locations between said helical coil and said winding frame after said helical coil has been formed by withdrawing said wedge members in a direction opposite to said axial taper.

* * * * *

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United States Patent [19]

McCarrick

[11] Patent Number: 5,604,972

[45] Date of Patent: Feb. 25, 1997

[54] METHOD OF MANUFACTURING A HELICAL ANTENNA

[75] Inventor: Charles D. McCarrick, Plymouth, Mass.

[73] Assignee: AMSC Subsidiary Corporation

[21] Appl. No.: 481,995

[22] Filed: Jun. 7, 1995

Related U.S. Application Data

[62] Division of Ser. No. 58,079, May 10, 1993, Pat. No. 5,485,170.

[51] Int. Cl.[6] H01P 11/00

[52] U.S. Cl. 29/600; 138/122; 156/175; 343/895

[58] Field of Search 29/600; 138/122, 138/154; 343/895; 156/175

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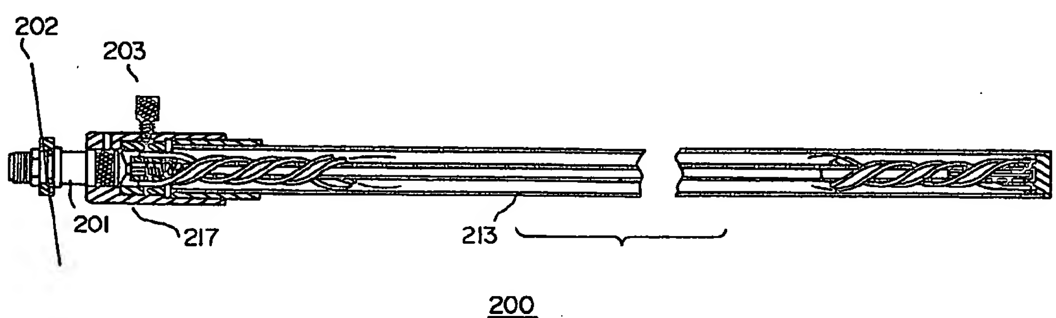
5,396,698	3/1995	Orthmann et al.	29/600

Primary Examiner—Carl J. Arbes
Attorney, Agent, or Firm—Lowe, Price, LeBlanc & Becker

[57] **ABSTRACT**

A mobile vehicular antenna for use in accessing stationary geosynchronous and/or geostable satellites. A multi-turn quadrifilar helix antenna is fed in phase rotation at its base and is provided with a pitch and/or diameter adjustment for the helix elements, causing beam scanning in the elevation plane while remaining relatively omni-directional in azimuth. The antenna diameter and helical pitch are optimized to reduce the frequency scanning effect. A technique is provided for aiming the antenna to compensate for any remaining frequency scanning effect.

24 Claims, 8 Drawing Sheets



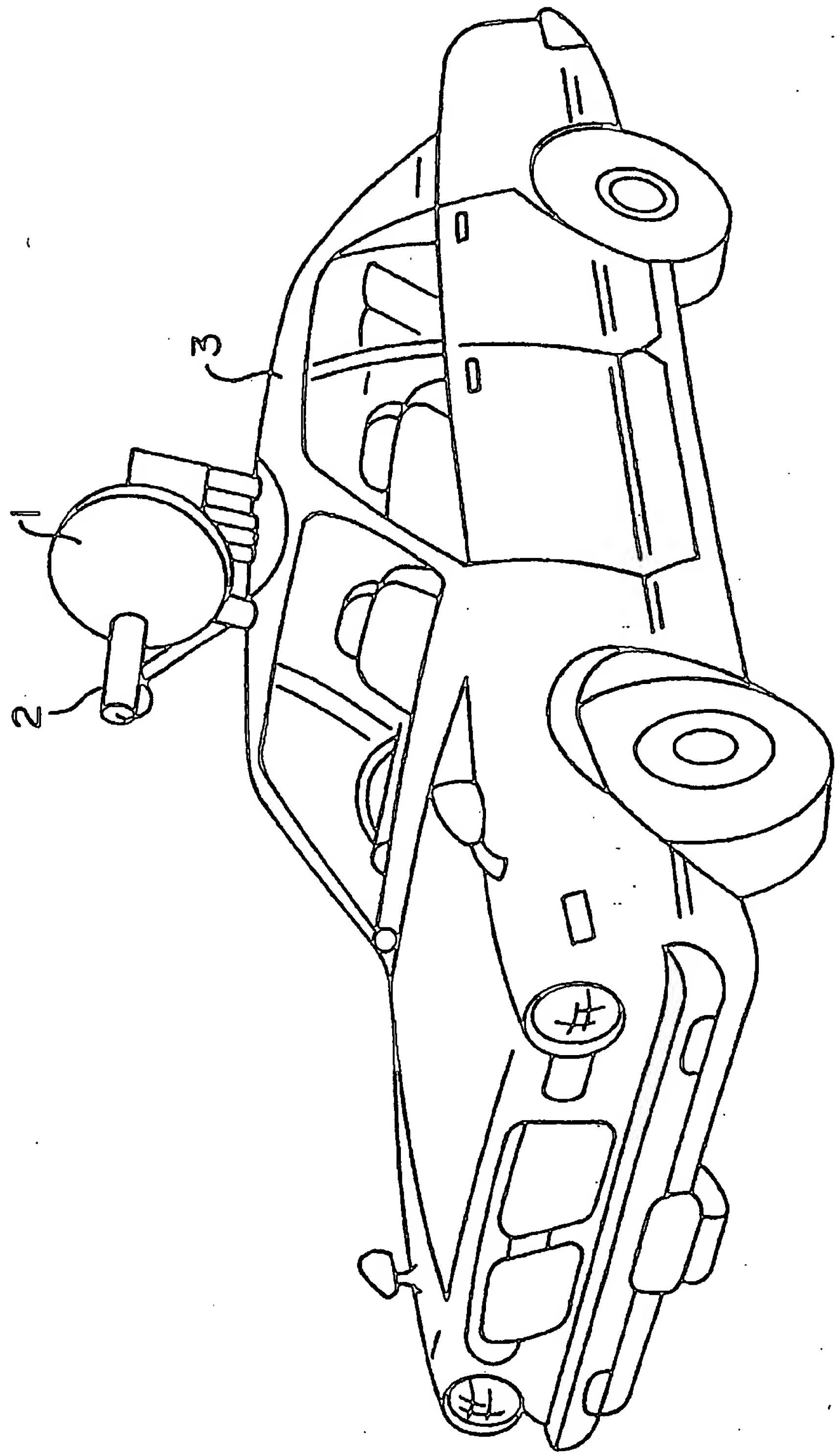


FIG. 1
PRIOR ART

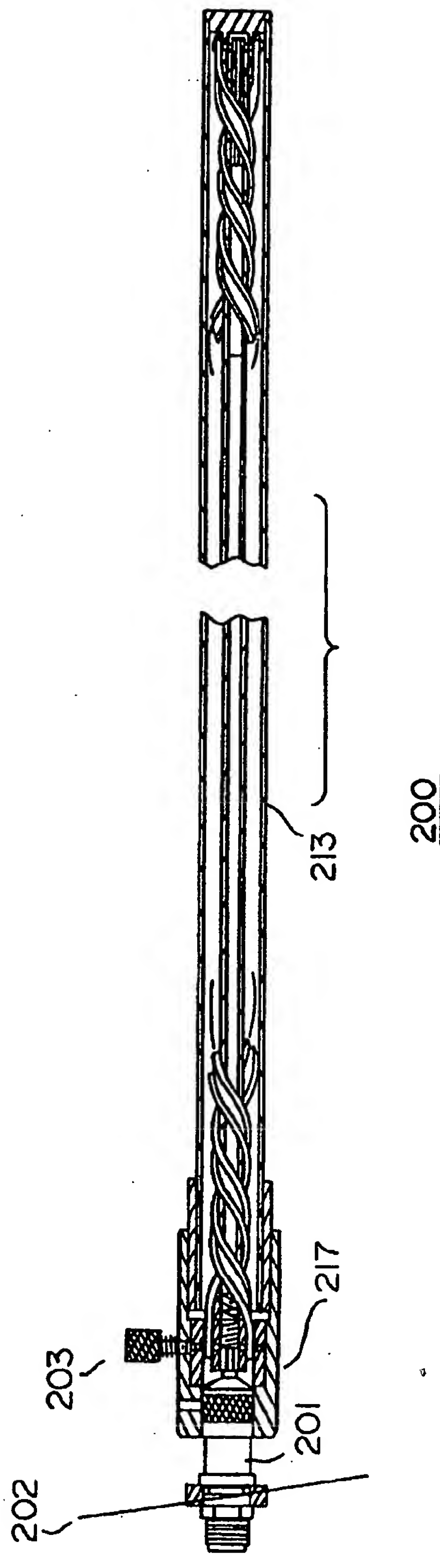


FIG. 2

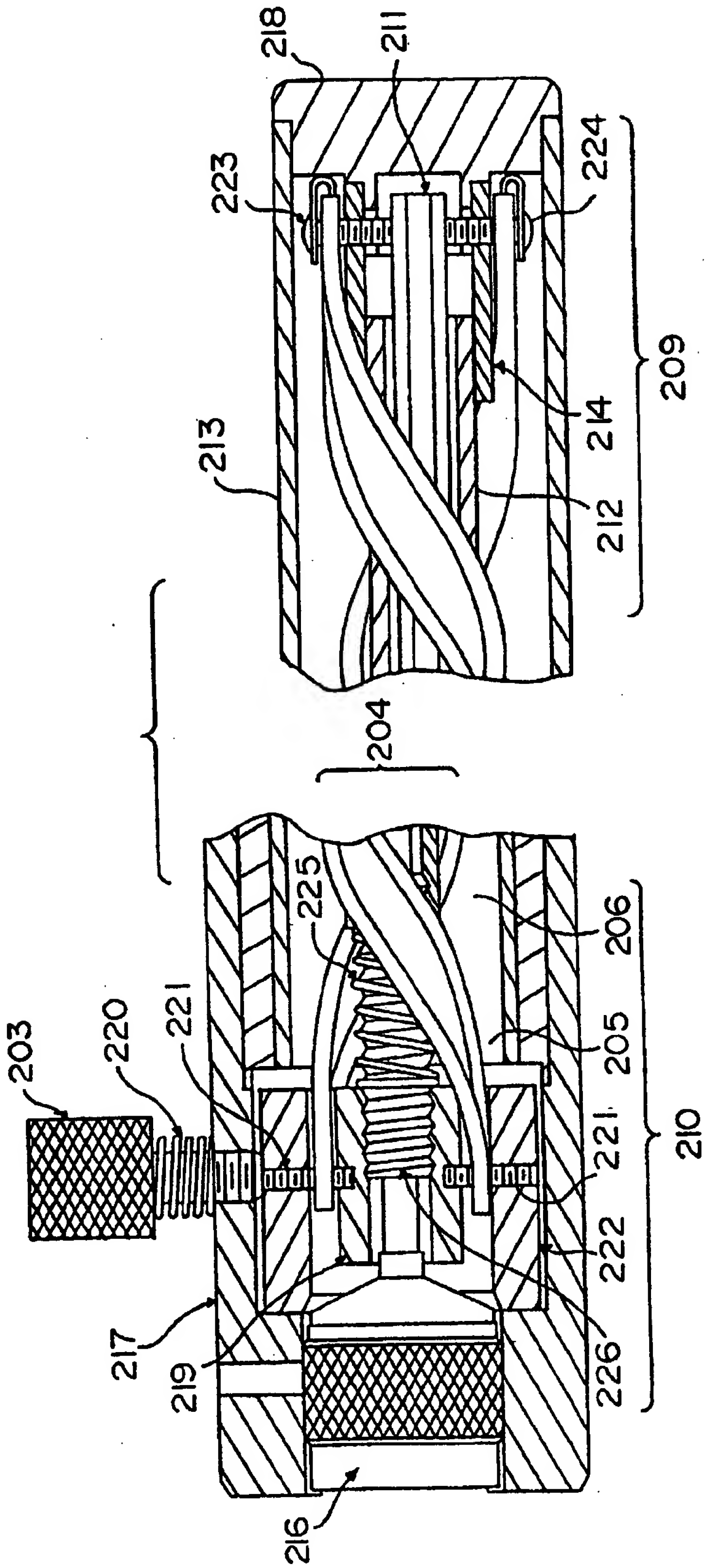

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FIG. 2A

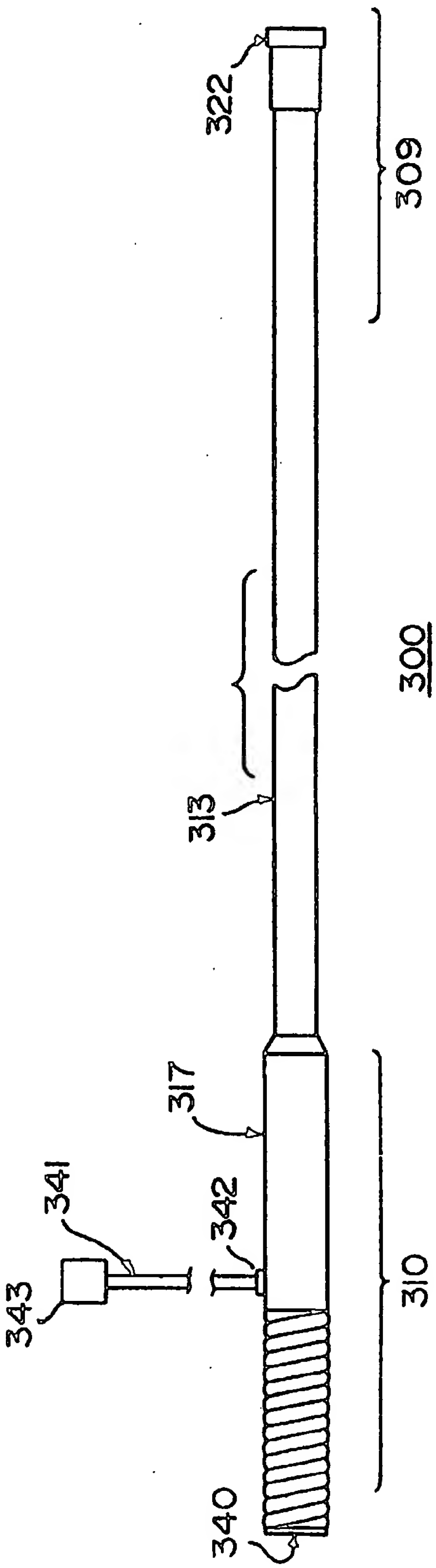

FIG. 3

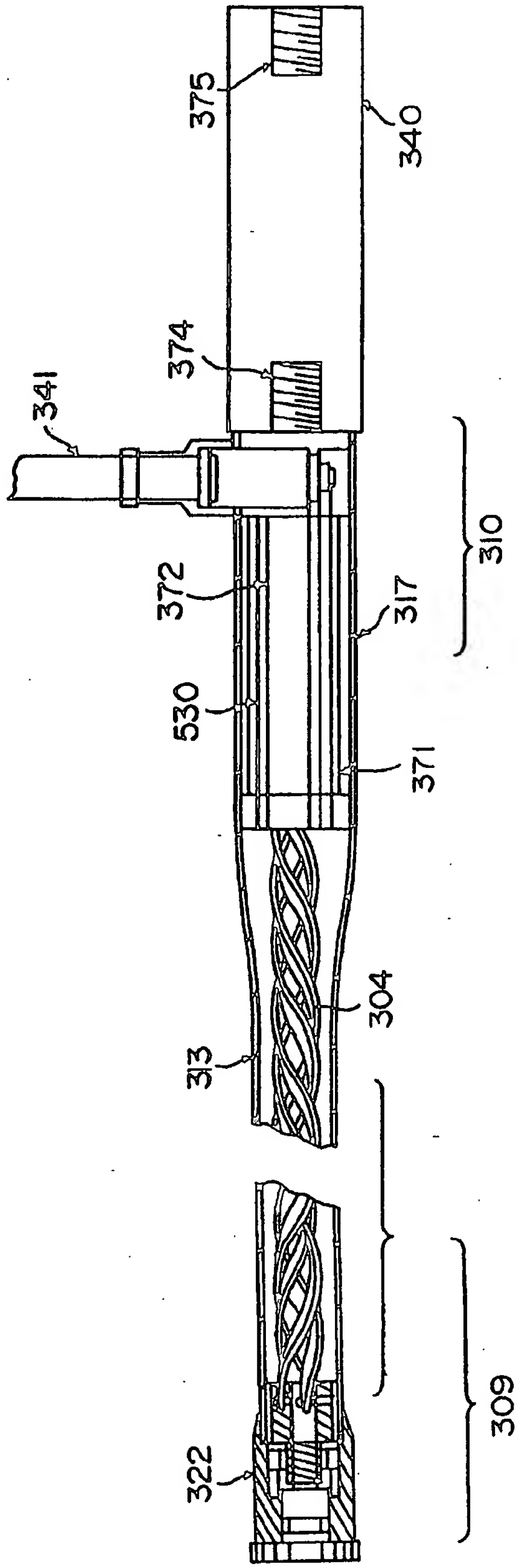

FIG. 3A

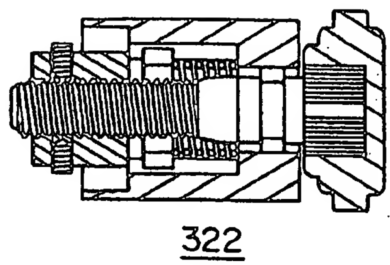

FIG. 4

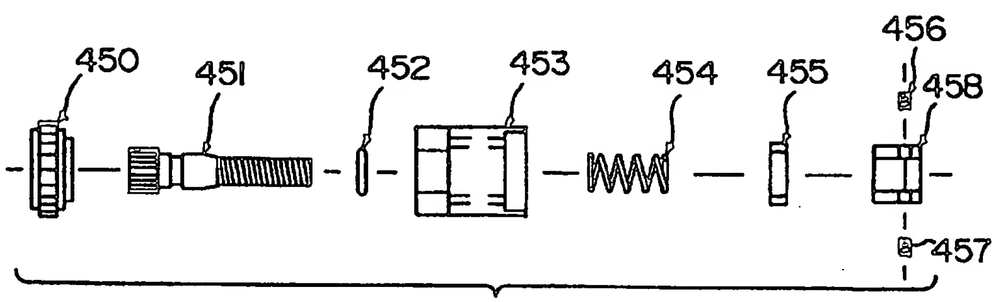

FIG. 4A

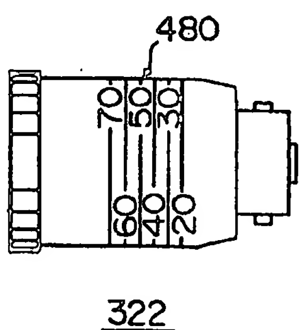

FIG. 4B

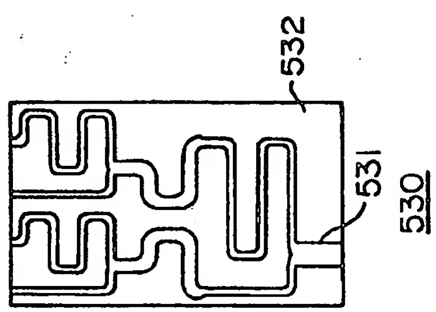

FIG. 5

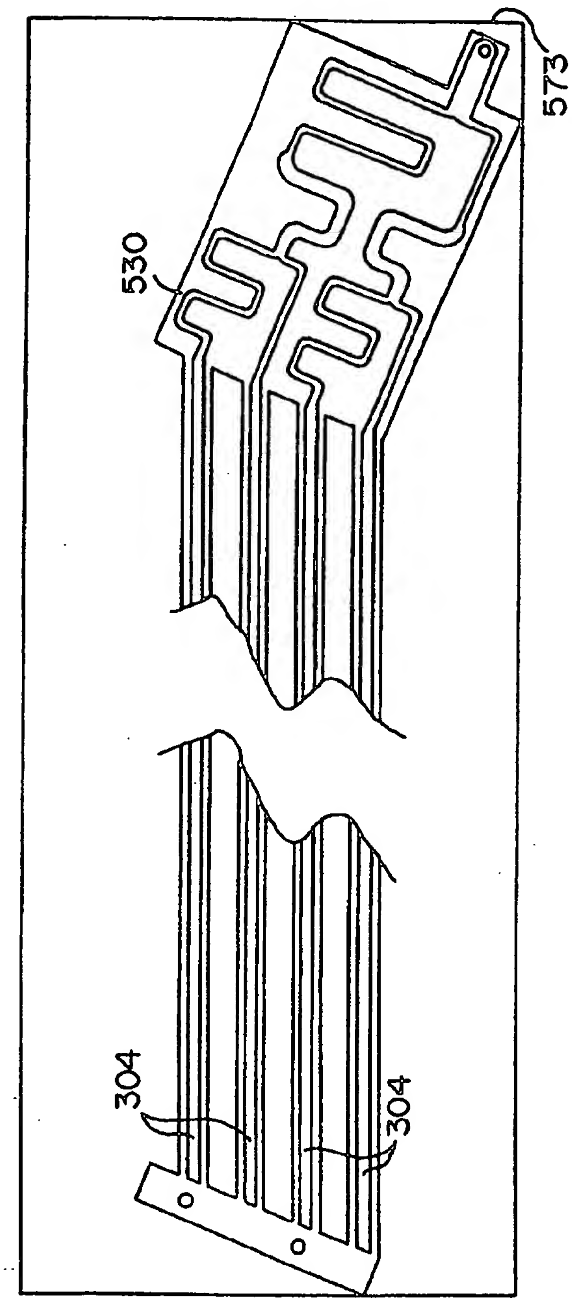

FIG. 5A

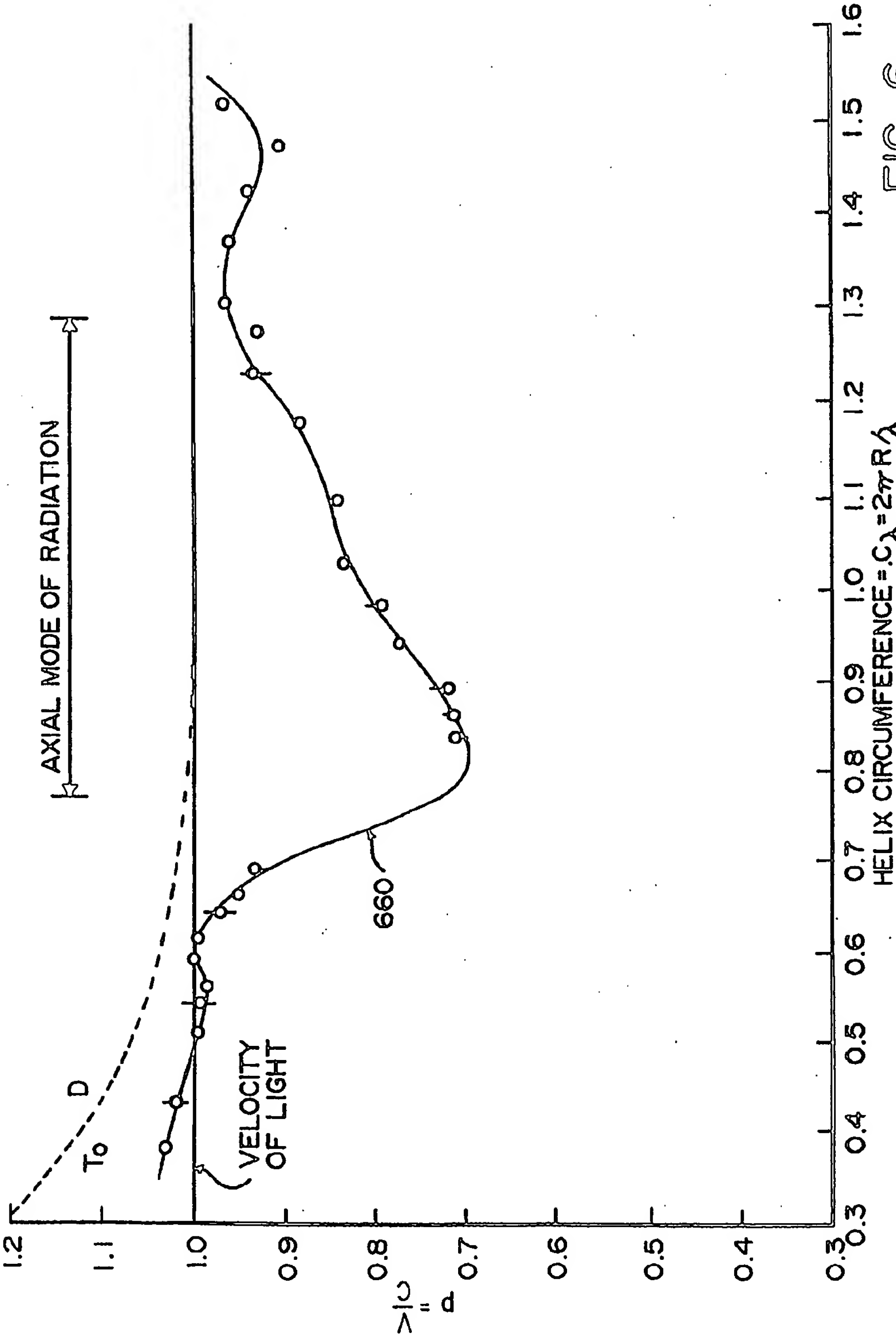
AXIAL MODE OF RADIATION
D
To
VELOCITY OF LIGHT
660
$p = \frac{V}{c}$
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
HELIX CIRCUMFERENCE = $C_\lambda = 2\pi R/\lambda$

FIG. 6

METHOD OF MANUFACTURING A HELICAL ANTENNA

This application is a division of application Ser. No. 08/058,079 filed May 10, 1993, now U.S. Pat. No. 5,485,170 issued Jan. 16, 1996.

TECHNICAL FIELD

The present invention relates to radio transceiver antennas, more particularly mobile vehicular antennas for use in accessing stationary geosynchronous and/or geostable satellites.

BACKGROUND ART

Mobile communications systems are known in the art for providing a communications link between a mobile vehicle (e.g., automobile, truck, train, airplane or the like) and stationary base or another mobile vehicle. Communications link, as used in the present application is defined, but not limited to voice, data, facsimile or video transmission or the like. Some such known systems utilize local radio transmitters and receivers, for example, various radio dispatched vehicles (taxis, police, deliveries, repair services, or the like) ham or amateur radio, Citizens Band Radio (CB), commercial transmitters, cellular systems or the like.

The disadvantage of these local radio frequency devices is that they provide only a limited scope of coverage. Practical limitations in transmitter and receiver design as well as bandwidth considerations limit the range of such systems. For some applications, for example, commercial transportation (e.g., shipping; common carriers and the like) it is desirable to provide communications coverage for a larger area, such as the continental United States (CONUS). Such coverage is possible with a series of local transmitter stations strategically located throughout the CONUS area, however, the practical limitations of maintaining and operating such a large number of transmitting stations renders such a system too costly and impractical. Further, even if such a system were implemented, coverage over the entire CONUS could not be assured, as "blackout" areas could arise due to local terrain and weather conditions.

As such, it has been proposed to provide a Mobile Satellite Communications system (MSAT) for use in providing a communications link between one or more stationary bases and mobile vehicles, or between stationary bases or between mobile vehicles. Satellite communications systems are known in the art and have been extensively used in the telecommunications and television arts. For example, a satellite can be placed in a geosynchronous and/or geostable orbit with a broadcast "footprint" which covers the entire CONUS. Of course, other "footprint" sizes could also be used to cover other geographic areas. Further, multiple satellites could also be used to provide a plurality of "footprints" (overlapping or not) to cover a particular area or areas.

The use of a satellite system overcomes many of the disadvantages of local radio frequency networks. For example, it is possible, with a satellite system, to use one satellite transponder to provide a common data link with a plurality of vehicles or sites throughout the CONUS. The use of new, so-called "high power" satellite transponders in higher frequency bands (e.g., Ku-band, L-band and the like) makes possible a more robust, stronger signal which can be more readily received throughout the entire CONUS.

Such a strong signal is desirable in mobile applications in particular as constraints are placed on antenna design. For example, in early telecommunications and television applications, so called "low" power satellite transponders (on-the order of tens of watts) provided a fairly weak signal which generally required a fairly large antenna to receive. Typical terrestrial antennas were parabolic designs (or variants thereof) on the order of at least a meter or more in diameter, utilizing low noise amplifiers to amplify the relatively weak received signal.

For mobile applications, a more compact, relatively omnidirectional antenna is desirable. Aerodynamic and aesthetic requirements necessitate that the antenna design be small and relatively short. Further, the antenna must also be robust in order to survive in a mobile (e.g., automotive) environment. In addition, if such a system is to be widely adopted, the antenna design must be relatively inexpensive in order to keep the overall cost of the mobile transceiver down. Since the communications link between the satellite and the antenna is more or less a line of sight transmission link and since a mobile vehicle is rarely positioned in one location for any given period of time, an efficient, relatively omnidirectional antenna is needed.

Thus, prior art parabolic antenna designs are impractical for mobile use. Such antennas are relatively large and expensive and largely unidirectional. For mobile applications, an antenna positioning device would be needed to constantly reposition the antenna for optimum reception. Furthermore, such an antenna design would be much too bulky for mobile application, presenting too large a surface for aerodynamic considerations, and presenting a generally displeasing aesthetic appearance. Moreover, in mobile applications, such an antenna design would be too delicate to survive long. Low hanging branches, parking garages and other aerial hazards would quickly destroy such a large antenna.

An example of one such mobile parabolic dish design is shown in Suzuki et al. U.S. Pat. No. 4,725,843, issued Feb. 16, 1988 shown in FIG. 1. FIG. 1 shows a vehicle 3 with parabolic dish antenna 1 and feed horn 2. As can be readily ascertained from FIG. 1, the relatively large dish antenna 1 precludes the use of any rooftop accessories (e.g., roof rack or the like) and presents quite a profile to the wind. In addition, such a design is somewhat aesthetically displeasing, thus precluding mass consumer acceptance. Such mobile satellite communications systems have consumer applications and as such, a pleasing aesthetic design is a necessary criteria. The parabolic dish 1 of FIG. 1 also requires a positioning mechanism to constantly reposition dish 1 as vehicle 3 travels. Such a positioning system is complex and fragile, adding to the cost and maintenance of the unit and detracting from the reliability and robustness of the design. Finally it is noticeable that the design of FIG. 1 is particularly susceptible to damage due to low clearances such as garages and the like.

A practical MSAT antenna must also be able to compensate for changes in latitude. In particular, as a vehicle travels from areas of high latitude (e.g., Northern CONUS) to areas of lower latitude (e.g., Southern CONUS), the angle of elevation between the vehicle and the satellite changes (e.g., from 20° to 60°). Thus it remains a requirement to provide an antenna which, although maintaining relatively omnidirectional coverage in the azimuth, is capable of scanning its main radiation beam in elevation to compensation for changes in latitude.

For applications in which it is desirable to provide both transmit and receive capabilities in the mobile unit, the

antenna must also be able to efficiently transmit radio signals to the satellite and receive return signals as well. In typical radio communications systems, different frequencies are chosen for the transmit and receive signals in order to prevent interference between these two signals. Unfortunately, most antenna designs are optimized for one frequency or a range or band of frequencies. As with all travelling wave antennas, the location of the peak radiation beam varies with frequency, giving rise to a phenomenon called "frequency scanning". This phenomena results in an unfortunate reduction in antenna gain between the transmit and receiving modes of operation. This reduction in gain is sometimes called "cross-over loss".

Thus, it remains a requirement in the art to provide a small, inexpensive, efficient vehicular MSAT antenna which has relatively omni-directional coverage in azimuth. It remains a further requirement in the art to provide an MSAT antenna which has an aesthetically pleasing and robust design. It remains a further requirement in the art to provide an MSAT antenna which is capable of scanning its main radiation beam in elevation while remaining relatively omni-directional in azimuth. It remains an even further requirement in the art to provide a vehicular MSAT antenna with reduced frequency scanning.

The present invention solves these and other problems by providing a multi-turn quadrifilar helix antenna fed in phase rotation at its base. The antenna of the present invention provides for an adjustment of the helix elements, causing beam scanning in the elevation plane. The quadrifilar helical antenna is omni-directional in azimuth, making the antenna particularly suitable for a mobile vehicular antenna accessing stationary satellites.

OBJECTS OF THE INVENTION

Thus, it is an object of the present invention to provide an MSAT antenna which is reduced in size.

It is a further object of the present invention to provide an MSAT antenna which is inexpensive to produce.

It is a further object of the present invention to provide an MSAT antenna which efficiently transmits and receives radio frequency signals.

It is a further object of the present invention to provide an MSAT antenna which has relatively omni-directional coverage in azimuth.

It is a further object of the present invention to provide an MSAT antenna with a robust design capable of withstanding a vehicular environment.

It is a further object of the present invention to provide an MSAT antenna which is capable of scanning its main radiation beam in elevation while remaining relatively omni-directional in azimuth.

It is a further object of the present invention to provide a vehicular MSAT antenna with reduced frequency scanning characteristics.

DISCLOSURE OF THE INVENTION

The MSAT antenna of the present invention comprises a multi-turn helix antenna having at two elements fed in anti-phase or three or more elements fed phase rotation at its base. The antenna of the present invention provides for an adjustment of the helix elements, causing beam scanning in the elevation plane.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a prior art mobile satellite antenna design.

FIG. 2 shows a cross-sectional view of a bifilar helical antenna of the present invention.

FIG. 2A shows an enlargement showing details of the bifilar helical antenna of FIG. 2.

FIG. 3 shows an exterior view of a quadrifilar helical antenna of the present invention.

FIG. 3A shows a cross sectional view of the quadrifilar helical antenna of FIG. 3.

FIG. 4 shows a cross-sectional view of the adjustment mechanism for the helix elements.

FIG. 4A shows an exploded view of the adjustment mechanism of FIG. 4.

FIG. 4B shows an exterior view of one embodiment of the adjustment mechanism of FIG. 4.

FIG. 5 shows a phased power combiner for use in the quadrifilar helical antenna of the present invention.

FIG. 5A shows a flexible circuit layout for a combined phased power combiner and quadrifilar helical antenna.

FIG. 6 shows a graph of relative phase velocity as a function of helix circumference used in modeling the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

FIGS. 2 and 2A show a multi-turn bifilar helix antenna (hereinafter "antenna") 200 using a mechanical design which permits the pitch and diameter of helix elements 205 and 206 to be adjustable. This mechanical adjustment elicits an electrical response in the radiation characteristics of antenna 200 which permits beam steering of the radiation pattern in the elevation plane. In the preferred embodiment antenna 200 is capable of scanning its main radiation beam from 20° to 60° in elevation while maintaining relatively omni-directional coverage in azimuth.

A range of 20° to 60° is particularly suitable for use in, the CONUS, as this range of elevation corresponds to the angles of inclination between a geostable satellite and locations throughout the CONUS. Other ranges of angles could, of course, be used if the antenna is to be used in another country or countries. A narrower range could be used in applications where the mobile vehicle is anticipated as having a limited range of travel. A fixed elevation angle could be chosen for stationary antennas or antennas using in local mobile applications. At the other extreme, an adjustment range could be provided from 0° (horizon) to 90° (zenith) to provide global coverage. The preferred range of 20° to 60° is shown here for use in the CONUS and is in no way intended to limit the scope of the invention.

The mast antenna of FIG. 2 is designed to mount to a detachable base 201 located on the vehicle skin (e.g., trunk, fender, roof or the like) 202. Its scanned radiation angle is set manually by the vehicle operator with the relatively simple adjustment of a knurled sleeve 222 at the base 217 of antenna 200.

Bifilar helix 204 comprises two helix elements 205 and 206 separated 180° apart, but sharing a common axis. In the preferred embodiment, helix elements 205 and 206 have conductors made of a highly conductive material, such as copper. Helix elements 205 and 206 serve as the radiating portion of the antenna. Helix 204 has distal end 209 and proximal end 210. In general, the distal end 209 of the

vertically mounted antenna 200 is the end which is furthest from the ground plane formed by vehicle skin 202. Antenna 200 is fed at distal end 209 with a balanced assembly comprising coaxial cable section 211 terminating in a balun 214. This distal feed technique is sometimes referred to as the backfire mode.

Helix elements 205 and 206 are formed by being wound around a constant diameter tube to form a uniform helix. The angle of pitch of helix 204 is determined by the number of helix turns for a given axial length. Pitch in unit length is defined as the axial length required for the helix to make one complete turn about its axis. When helix elements 205 and 206 are wound 180° apart as suggested above, a criss-cross effect of the elements is observed when the structure is viewed from the side as is shown in FIGS. 2 and 2A.

The spacing (helix diameter) and angle of pitch of helix 204 determines the polarization and radiation characteristics of antenna 200. A bifilar helix with left-handed helices (ascending counter-clockwise as viewed from the bottom) radiates a right-hand circularly-polarized (RHCP) wave which is relatively omni-directional in azimuth. If the pitch angle and or the diameter of helix 204 is increased from an initial reference point, the radiation in elevation is scanned towards the horizon. In the present invention, the element pitch angle and helix diameter are adjusted by varying the number of helix turns for a fixed axial length.

In one embodiment, helix elements 205 and 206 are made from 300 ohm twin lead line commonly used in FM receivers and some television leads. One of the conducting leads is removed from the polypropylene sheathing of each of helix elements 205 and 206, while the remaining lead serves as the radiating element. Thus, helix elements 205 and 206 each contain only one wire.

Polypropylene was chosen because it readily takes a helix shape when wrapped around a metal tube (not shown) and heated with a hot air gun. Other heating techniques can also be used including heating the metal tube itself. In the embodiment shown in FIGS. 2 and 2A, helical elements 205 and 206 were formed from two 37 inch lengths of 300 Ohm twin lead line suitably modified as discussed above by stripping one of the leads from the sheathing. When wound six and one-half time around a ⅝ inch diameter tube, helical elements 205 and 206 are formed at an axial length of about 31 inches.

Formed helix elements 205 and 206 are placed over a 31 inch long ⅜ inch diameter hollow supporting tube 212 which may be made of any fairly robust insulating material such as phenolic resin. Supporting tube 212 is centrally located within a 32 inch long outer sheath 213 which is one inch in diameter. Outer sheath 213 also may be formed of any robust insulating material such as polycarbonate and serves to provide environmental sealing of the antenna assembly. Coaxial cable 211 is fed through the center of supporting tube 212 and is terminated at the distal end 209 at balun 214. Coaxial cable 211 may be formed from a UT141 semi rigid coaxial line.

Balun 214 comprises a hollow 3/16 inch diameter brass tube with two feed screws 223 and 224 located 180° apart. The wire portions of Helix elements 205 and 206 are secured to the termination of balun 214, one on each side, by feed screws 223 and 224. Proximal end 210 of coaxial line 211 is terminated by connector 216 which may be press fitted into base 217 of antenna 200. Balun 214 serves to maintain a relative phase difference of 180° between the radiating elements for the required frequency bands.

In an alternative embodiment, balun 214 comprises a hollow 3/16 inch diameter slotted brass tube with two slots in the tube located 180° apart. The slots are 0.124 inches wide by 1.85 inches long. The wire portions of Helix elements 205 and 206 are soldered to the termination of balun 214, one on each side, separated by the slots.

Support tube 212 is captured at distal end 209 by end cap 218 set into distal end 209 of outer sheath 213 so as to prevent support tube 212 from rotating. End cap 218 is secured to distal end 209 of outer sheath 213 by glue, screws, threading, press fit, or the like.

Proximal end 210 of support tube 212 is movably attached to inner rotatable sleeve 219 by threaded member 226. Threaded member 226 may be, for example, a 1/4-20 threaded stainless steel sleeve. Spring 225 is installed at the point of rotation between support tube 212 and inner rotatable sleeve 219 to prevent undesired relative movement between inner rotatable sleeve 219 and support tube 212. Spring 225 may be made of, for example, stainless steel. Inner rotatable sleeve 219 is held in place by at two set screws 221 within knurled adjustment outer sleeve 222. Inner sleeve 219 and outer sleeve 222 are located within base 217 which supports outer sleeve 213 and connector 216. The two grounded ends of helix elements 205 and 206 are attached to rotating set screws 221, creating a mechanism for changing helix pitch. Access to knurled outer sleeve 222 is made by machining two window slots (not shown) in the base 217. Base 217, inner sleeve 219 and outer sleeve 221 may be made from any suitable insulating plastic material with requisite strength requirements, such as DELRIN (TM) plastic.

Helix 204, preferably made of polypropylene, has the desirous property of maintaining a uniform pitch along its axial length, even when one end is rotated with respect to the other. By fixing proximal end 209 of helix elements 205 and 206 from rotation to balun 214 and attaching proximal ends 210 of helix elements 205 and 206 to rotatable outer sleeve 222, an elevation steerable antenna with fixed height and adjustable pitch is achieved.

In operation, the operator loosens knurled locking bolt 203 (held firm by spring 220) and twists knurled outer sleeve 222 through the two window slots (not shown) to adjust the axial pitch of antenna 200. In its initial position, helix elements 205 and 206 make approximately six and one-half turns within the axial length of antenna 200. This allows for coverage within 20° above the horizon. In the other extreme, helix elements 205 and 206 make just under ten complete turns, allowing for coverage up to 60° above the horizon. A mechanical limiter (not shown) and elevation angle indicator (not shown) are used to prevent the user from forcing the helix elements beyond their six and one-half and ten turn limits and to simplify the process for optimizing the antenna for elevation coverage. The operator's choice of elevation angle can be determined from the latitude where the vehicle is located, or can be positioned with the aid of an electronic antenna peaking device as discussed below in connection with the second preferred embodiment.

FIGS. 3 and 3A show a quadrifilar antenna 300 which is a second preferred embodiment of the present invention. Mast antenna 300 is a multi turn quadrifilar helix antenna fed in phase rotation at its base. In a similar manner to the bifilar antenna 200 discussed above in conjunction with FIGS. 2 and 2A, the antenna 300 of FIG. 3 allows the pitch of the helix elements to be adjusted, causing beam scanning in the elevation plane.

A characteristic exists within this or other antenna designs which can potentially adversely affect its utility as a medium gain omni-directional antenna if not properly accounted for.

As with all travelling wave antennas, the location of the peak radiation beam varies with frequency, giving rise to a phenomenon sometimes called "frequency scanning". Frequency scanning can sometimes result in a reduction of antenna gain between the transmit and receive modes of operation, since the transmit and receive frequencies can differ from each other. For example, in the present invention, the MSAT system for which the antenna of FIG. 3 was designed uses a receive frequency of 1525 to 1559 Mhz and a transmit frequency of 1626.5 to 1660.5 Mhz. This reduction in gain due to frequency scanning is sometimes referred to as "cross-over loss".

In the past, it was proposed that a helix antenna could be modeled as a wave guiding structure capable of supporting several distinct transmission modes each dependent on its particular phase velocity. These relative phase velocities are governed by the physical helix parameters of diameter and pitch, and so the relationship between the guided wavelength and its supporting structure becomes a two-fold problem over that of prior art rectangular waveguide arrays.

FIG. 6 plots the relative phase velocity as a function of the helix circumference in freespace wavelengths and illustrates the varying wavelength ratio which gives rise to scanning of the main beam. Segments of measured curve 660 that have a near zero slope (i.e.,. horizontal) identify a mode of operation in which frequency scanning is at a minimum. Note that these segments near unity correspond to a transition between transmission modes. This correlates with previous observations made on other types of mast antennas which indicated that as their diameter is decreased to a point near the transition between endfire and backfire transmission modes, the frequency scanning behavior decreases.

The key to minimizing scanning effects lies in the a priori knowledge of a relationship between the pertinent helix parameters and the induced phase velocities (or guided wavelengths). The waveguide-fed array is not in itself an adequate model because unlike the helix, its element sources are unique and plainly defined. The quadrifilar helix, being fed in (imbalanced) phase rotation, complicates matters still worse, and very little is offered in the prior art for to aid in providing a solution for the determination of its phase velocity. Thus the present invention encompasses an analytical procedure for providing adequate modeling of a quadrifilar helix antenna.

Computer-based modeling done on the helical antennas of the present invention was provided using the MININEC wire analysis code. This computer code uses a moment method technique to solve for the current distribution on a specified geometry of finite radius wire elements. Once the antenna geometry has been input and evaluated, an output file is generated containing the relative phase and amplitude of the current distribution at periodic points along the antenna structure. From this output file, it is possible to determine the guided wavelength for a given set of physical parameters, thereby resolving the problem of obtaining a controlled model.

From this output file a plot of relative phase velocity versus helix diameter can be generated specifically for the quadrifilar mast. From this plot, it is possible to determine the optimum mast antenna dimensions which will satisfy the goal of minimizing frequency scanning. From this data, it has been determined that the traveling wave increases speed with decreasing diameter corresponding to a mode transition from backfire to endfire. To maintain the necessary beam coverage, however, the helix pitch must also be adjusted. Frequency scanning thus decreases with a corresponding

decrease in antenna diameter. From this information, it was determined that an optimal pair of pitch and diameter parameters can be chosen to result in a reduction in frequency scanning.

For the quadrifilar antenna of FIG. 3 and 3A, it was determined that for the 60° limit of elevation, a diameter of 0.40 inches and a pitch of 9 turns over the 30 inch length (pitch=3.35 inches) was optimum. For the 20° limit of elevation, a diameter of 0.50 inches and a pitch of 6 turns over the 30 inch length (pitch=5 inches) was optimum. These dimensions reduced the frequency scanning effect to 4° objective at 20° elevation, 6° objective at 40° elevation, and 9° at 60° elevation. That is to say, that the difference between the elevation of the peak radiation beam in the transmit and received modes was 4°, 6° and 9° for a given elevation setting of 20°, 40° and 60°, respectively. This effectively reduces the frequency scanning effect by at least 2° to 4° over the bifilar antenna 200 of FIGS. 2 and 2A.

As discussed above, nearly equal to the operational performance of the antenna is its appearance to the user and its durability in a vehicular environment. Antenna 300 is thus fitted with a fiberglass radome (outer sheath) 313 to improve appearance and to increase the robustness of the design. A power combiner 530 for the four helical elements 304 of antenna 300 is housed in an enlarged base section 317 of radome 313. A neatly styled elevation adjustment knob assembly 322 is placed at distal end 309 of antenna 300 to adjust the pitch of the four helical elements 304 of antenna 300. The structure of adjustment knob 322 is discussed below in conjunction with FIGS. 4 and 4A.

Radome 313 is constructed from a fiberglass tube with 0.030 inch walls and a 0.625 inch diameter. This reduced diameter improves the appearance of the antenna such that it is nearly indistinguishable from ordinary CB or ham radio antennas currently in use. Of course, materials other than fiberglass may be used, such as polycarbonate or the like so long at the material is relatively stiff, non-conductive, and provides some impact resistance. Fiberglass was chosen here for its relative stiffness, low cost and ability to flex under impact for low clearance hazards.

For the quadrifilar helix antenna 300, an optimum helix diameter was determined (using the procedure discussed above in conjunction with FIG. 5) to be approximately 0.40 inches, which can easily be accommodated in the 0.625 inch diameter radome. Microstrip feeding circuitry, discussed below conjunction with FIG. 5, was designed in a cylindrical shape so as to be incorporated in to the antenna itself. The cylindrical microstrip feeding circuitry, however, requires an increase in diameter of radome 313 from 0.625 inches to 0.75 inches in diameter in enlarged base section 317. Enlarged base section 317 of radome 313 may be, for example, 3.75 inches long to accommodate the feed circuitry. The remaining 0.625 inch diameter portion of radome 313 is approximately 30 inches in length, approximately the same size and shape as existing CB or ham radio antennas.

FIG. 5 shows the power combiner circuit of the present invention. Power combiner 530 is made from a conductor bonded to a flexible film to form a flexible circuit. In the preferred embodiment, power combiner 530 is etched out of copper 531 on 5 mil thick MYLAR, a thin, strong polyester film film 532. The four helical elements 304 of antenna 300 are fed in quadrature phase rotation through a 4 into 1 power combiner 530 which may be etched on the same sheet of MYLAR as helical elements 304, as will be discussed below in conjunction with FIG. 5A. Power combiner 530 provides the necessary phase rotation to the four helix elements of

antenna 300 for circular polarization. Power combiner 530 forms a covered microstrip transmission line medium when "sandwiched" between two polypropylene tube sections 371 and 372 and then slid over a brass rod (not shown) which acts both as a transmission line ground plane and mounting base. In one embodiment, Power combiner 530 is sandwiched between two tubular sections of 0.063 inch wall polypropylene 371 and 372 which act as microstrip super- and substrates, respectively. This assembly is then slid over a brass rod (not shown) which acts as a ground plane and completes the circuit. One end of this brass rod extends beyond the end of radome 313 and connects to mounting spring 340 for mounting purposes.

A hole (not shown) is drilled through the brass rod (not shown) perpendicular to its line of axis and permits access for connecting cable 341 which has its center input soldered to the input port of power combiner 530. The outer conductor (not shown) of connecting cable line 341 is soldered to a ferrule (not shown) which retains a securing nut, thereby securing and providing electrical contact between the brass rod (not shown) and the outer conductor (not shown). Connecting cable 341 exits antenna 300 at the bottom end of enlarged base section 317 through a grommet seal 342 and serves as a feed line. Connecting cable 341 may be constructed, for example, of a twelve inch length of RG-304/U cable terminated in a TNC connector 343.

The four helical elements 304 may be made of polypropylene 300 Ohm twin lead antenna cable as discussed above in conjunction with FIGS. 2 and 2A. However, in the preferred embodiment, these elements can be formed from copper etched on a MYLAR film as shown in FIG. 5A. One advantage of making helical elements 304 using copper on MYLAR film is that since the power combiner 530 is also formed on a MYLAR film, the two can be combined as a single circuit, thus eliminating many soldering and assembly operations and reducing cost. FIG. 5A shows a technique for laying out both power combiner 530 and helical elements 304 onto one sheet of MYLAR film 573. Mylar film 573 can then be cut, for example, through a die cutting process, to produce the assembly of power combiner 530 and four helical elements 304. The MYLAR film has the advantage of not requiring thermoforming. Mylar film based helical elements 304, if cut in the proper shape, will readily assume and maintain a helical configuration without thermoforming. Of course, other materials other than MYLAR may be used so long as the material is suitably flexible to allow the helical elements 304 to be bent in a helical shape and that the material successfully bonds with the circuit elements. Similarly, although copper is shown here as comprising helical element 304, other conductive materials may also be used.

To improve the robustness of the design, spring base 340 is provided to absorb shock on impact between the antenna and low clearance objects (e.g., garage doors, tree limbs and the like). Spring base 340 may be one inch diameter and three inches in length. On both ends of the spring base 340 are tapped inserts 374 and 375. The brass rod (not shown) discussed above, extending from the base section 317 of radome 313 is threaded at one end of spring base 340 into tapped insert 374. A universal ball mount (not shown) is threaded into the other end of spring base 340 into tapped insert 375. The bottom of ballmount (not shown) is tapped to accept a single mounting bolt (not shown) which has its head secured beneath the mounting surface of the vehicle. In the preferred embodiment, all threaded mounts are standardized to a 5/16–18 thread.

As in antenna 200 of FIGS. 2 and 2A, a knurled knob 322 is provided on antenna 300 to provide adjustment of the antenna beam in the elevation plane. In the antenna 300 of FIG. 3, however, this knob is located at the distal end 309 of antenna 300. Locating adjustment knob 322 at distal end 309 of antenna 300 improves the overall appearance of antenna 300, simplifies construction, and discourages unnecessary tampering with the elevation adjustment of antenna 300.

Adjustment knob 322 is shown in cross-sectional detail in FIGS. 4 and 4A and in exterior detail in FIG. 4B. Adjustment knob 322 is designed as a separate piece part for simple assembly to radome tube 313 and helix elements 304. A moving travel limiter may be used as a vernier for fine peak adjustment as will be discussed below in conjunction with FIG. 4B.

Referring now to FIGS. 4 and 4A, adjustment knob 322 comprises knurled knob 450 which is press fit onto a splined end of threaded shaft 451. Threaded shaft 451 may be formed from a commercially available socket head cap screw. Threaded shaft 451 passes through weather sealing O-ring 452 into knob housing 453. Adjustment housing 453 is fixedly attached to distal end 309 of radome 313 by the use of screws, glue or the like. Threaded shaft 451 passes through compression spring 454 and travel limit nut 455 and connects threadably to mounting/retaining ring 458. Threaded shaft 451 is secured to mounting/retaining ring 458 and the helical elements 304 of antenna 300 by set screws 456 and 457.

In operation, when knurled knob 450 is turned, mounting/retaining ring 458 turns as well, altering the pitch of the helical elements 304 in a similar manner as discussed above in conjunction with FIGS. 2 and 2A. Travel limit nut 455 is slotted (not shown) and rides on corresponding ridges (not shown) in knob housing 453. Pressure between compressing spring 454, travel limit nut 455, and knob housing 453, prevents threaded shaft 451 from turning on its own due to vibration or the like. In addition, travel limit nut 455 limits the amount of travel of the mounting/retaining ring 458. When knurled knob 450 is turned to one extreme, travel limit nut 455 will seat against compressed compression spring 454, preventing any further movement. When knurled knob 450 is turned in the other extreme, travel limit nut 455 will seat against mounting/retaining ring 458, also preventing any further movement. Thus, travel limit ring 455 prevents the user from over adjusting antenna 300 and possibly damaging the MYLAR based helixes 304.

Antenna 300 can be adjusted by means of indicia marked on the outside of knob housing 453, indicating relative angles of elevation as is shown in FIG. 4B. Knob housing 453 can be made of a clear plastic such as acrylic plastic, so that the position of travel limit nut 455 is easily visible to the user. Alternately other techniques can be used, such as modifying travel limit nut 455 to include an indicator or pointer to extend through a slot in knob housing 453. The use of clear plastic, however, allows the unit to remain weather tight.

In use, the antenna is designed to be adjusted by the user, for example, a truck driver or the like. Relative latitude and angle of elevation information can be converted to a simple table for use by the user, for example, listing cities or States, and the corresponding desired elevation setting for the antenna for those cities and States. By turning knurled knob 450 to adjust the antenna, a rough adjustment can be made which in most instances should be sufficient to properly adjust the angle of elevation so that the conical shaped beam of the antenna will intercept the geostable orbit of the satellite.

In addition, an electronic antenna peaking circuit (not shown) can be provided to provide an audible feedback to

the user when the antenna had been properly adjusted. Such a peaking circuit can be incorporated into the transceiver circuitry (not shown). When the antenna peaking circuit is activated, the user then adjusts the antenna until a particular tone or signal is heard, indicating the adjustment of the antenna is at optimum. A speaker or earphones can be provided to that the user can hear the audible tone or tones. Alternatively, a meter or other type of visual display can be used to indicate antenna signal strength or some other indication signal for purposes of optimizing antenna adjustment.

Further, it may be desirable to use a scheme for optimizing antenna adjustment which takes into account the frequency scanning effect (albeit reduced) present in the antenna. In operation, the user rotates knurled knob 450 counterclockwise to its limit (i.e., the "low" or 20° limit). This will set the elevation of the main radiation beam of antenna 300 to its lower limit of approximately 20°. The user then hits a "RESET" button (not shown) on the MSAT transceiver (not shown). The user then carefully rotates knurled knob 450 clockwise to its other limit (i.e., the "high" or 60° limit), slowly scanning the main radiation beam of antenna 300 upwards for 20° to 60°. The MSAT transceiver (not shown) measured the signal strength of the received signal and records the maximum values of the received signal.

The user then slowly rotates knurled knob 450 counterclockwise until a "beep" is heard from MSAT transceiver (not shown) through a speaker (not shown) or headphones (not shown). Again, as discussed above, a visual display could also be used (not shown). The "beep" indicates the event when the received signal changes to a value 1 Db less than the maximum signal value which was recorded during the upwards scan of the beam as discussed above. This peaking feature may be implemented by a sample-and-hold circuit (not shown) in the MSAT terminal with a resolution of 1 dB and an annunciator on the handset, or any other equivalent technique.

This strategy will permit near optimum beam steering. It will align the satellite onto the lower elevation side of the receive beam. Since the transmit beam of antenna 300 is always lower in elevation (for the given frequency values used) than the receive beam, the transmit beam will always be close to optimum. With this pointing strategy, the approximate angular misalignment from perfect received beam conditions is about 6 degrees. Thus, the actual pointing is within about 2 degrees of the crossover point between transmit and receive beams. By avoiding the condition where the antenna was peaked to the upper side of the receive beam, substantial improvements in beam pointing are afforded.

Of course, many other modifications are possible of the present invention without departing from the scope or spirit of the present invention. For example, while the antennas of FIGS. 2, 2A, 3 and 3A are discussed as being approximately 30 inches or more in length, other lengths could be used with suitable results. Since printed circuit technology is used in conjunction with the antenna of FIG. 3, these elements could be easily modified by top loading them with reactive elements. In the bifilar antenna, for example, shielding a portion of the structure opposite the feed end has little effect on antenna gain. The mast acts as a helical waveguide, with one section radiating and another section inducing that radiation, like a reactive element storing energy. The length of the non-radiating section could be easily reduced without affecting the travelling current on the rest of the structure. A reduced height antenna mast would provide an even more aesthetically pleasing appearance, reduce wind resistance and improve the robustness of the design by reducing the likelihood of low clearance collisions.

In addition, as discussed above, it had been discovered in testing that the bifilar helical antenna of the present invention, shielding a portion of the structure opposite the feed end has little effect on antenna gain. This confirms the premise that radiation currents are practically non-existent along the last few turns of the antenna. Experiments have shown that shielding the last eight inches (or more) of the antenna (as measured from the base) improved the axial ratio with little or no degradation in gain. Inserting the antenna through the ground plane to various positions along the shielded section improved the axial ratio further. Thus, the antennas of the present invention could be suitably modified to be mounted below the vehicle skin (e.g., eight inches or more) with only the remaining portion of the antenna showing. This mounting technique not only improves the axial ratio, but reduces overall mast height, improving the aesthetic appearance and reducing clearance hazards. This technique would be especially useful in manufacturing a retractable version of the antenna of the present invention.

Further, although the helical antenna of the present invention is disclosed as having two or four helical elements, other number of elements could successfully be used in other antenna configurations. In addition, although the helical elements are shown here as being equilaterally spaced about a central axis (180° for the two element antenna, and 90° for the four element antenna), other spacing arrangements could also be used, so long as the elements are symmetrically arranged about the axis.

It should also be noted that although the elevation adjusting knob of the present invention adjusts both the axial pitch and radial diameter of the helixes, the antenna could be configured to adjust either one of these variables independently of the other.

It will be readily seen by one of ordinary skill in the art that the present invention fulfills all of the objects set forth above. After reading the foregoing specification, one of ordinary skill will be able to effect various changes, substitutions of equivalents and various other aspects of the invention as broadly disclosed herein. It is therefore intended that the protection granted hereon be limited only by the definition contained in the appended claims and equivalents thereof,

I claim:

1. A method of manufacturing a helical antenna comprising the steps of:

cutting a section of flexible twin conductor antenna lead to a predetermined length, said twin conductor antenna lead having a first conductor and a second conductor surrounded by an insulating sheath,

wrapping said cut section of flexible twin antenna lead in a helix shape about a form of a predetermined diameter, to produce a wrapped lead, and

heating said wrapped lead to produced a thermoformed lead.

2. The method of claim 1 further comprising the step of:

removing said first conductor from said insulating sheath of said flexible twin conductor antenna lead, leaving the other conductor in place, after said cutting step and prior to said wrapping step.

3. The method of claim 1 wherein said insulating sheath of said flexible twin conductor antenna lead is formed of polypropylene.

4. A method of manufacturing a helical antenna comprising the steps of:

etching at least one conductive trace from a sheet of conductor bonded to a flexible film,

cutting said flexible film to a size substantially the same as said at least one conductive trace to produce at least one flexible antenna element, and

wrapping said at least one flexible antenna element in a helical form to produce at least one flexible helical antenna element.

5. The method of claim 4 further comprising the steps of:

forming a power combining circuit on said flexible film, said power combining circuit being coupled to one end of said at least one flexible antenna element, and

wrapping said power combining circuit in a tubular form prior to wrapping said at least one flexible antenna element in a helical form.

6. The method of claim 5, further comprising the steps of:

sliding said power combining circuit wrapped in tubular form, over a tube shaped substrate, and

sliding a tube shaped superstrate over said power combining circuit wrapped in tubular form.

7. The method of claim 6, further comprising the steps of:

sliding said tube shaped substrate over a tube shaped ground element,

securing said tube shaped ground element to a base for mounting said antenna,

securing one end of a tube shaped support tube to said base, and

coupling an other end of said at least one flexible helical antenna element to said an other end of said tube shaped support to produce an antenna assembly.

8. The method of claim 7 further comprising the step of: securing a radome to cover said antenna assembly.

9. The method of claim 7 wherein said coupling step further comprises the steps of:

securing said other end of said at least one flexible helical element to an adjustment means for adjusting the axial pitch of said helical antenna, and

securing said adjustment means to said tubular support element.

10. A method for aiming a helical antenna comprising at least one flexible helical element while compensating for frequency scanning effects comprising the steps of:

adjusting the pitch of said at least one flexible helical element to a predetermined lower limit so as to steer a receive beam of said helical antenna to a predetermined lower elevation,

adjusting the pitch of said at least one flexible helical element from said predetermined lower limit to a predetermined higher limit so as to scan said a receive beam of said helical antenna to from said predetermined lower elevation to a predetermined higher elevation,

measuring the signal strength of a signal received by said helical antenna during the second adjusting step,

recording the maximum value of said received signal measured during said second adjusting step,

adjusting the pitch of said at least one flexible helical element from said predetermined higher limit towards a predetermined lower limit so as to scan said a receive beam of said helical antenna to from said predetermined higher elevation towards a predetermined lower elevation,

measuring the signal strength of a signal received by said helical antenna during the third adjusting step,

generating an output signal indicative of the event when the received signal changes to a value 1 Db less than the maximum signal value recorded during the second adjusting step.

11. The method of claim 10 wherein said recording step is implemented by a sample-and-hold circuit.

12. The method of claim 10 wherein said generating step comprises the step of:

generating an audio signal indicative of the event when the received signal changes to a value 1 Db less than the maximum signal value recorded during the second adjusting step.

13. The method of claim 10 wherein said generating step comprises the step of:

generating a visual signal indicative of the event when the received signal changes to a value 1 Db less than the maximum signal value recorded during the second adjusting step.

14. A method of manufacturing a helical antenna comprising the steps of:

cutting a section of flexible twin conductor antenna lead to a predetermined length,

wrapping said cut section of flexible twin antenna lead in a helix shape to produce a wrapped lead, and

heating said wrapped lead to produced a thermoformed lead.

15. A method of manufacturing a helical antenna comprising the steps of:

etching at least one conductive trace from a sheet of conductor bonded to a flexible film,

cutting said flexible film to produce at least one flexible antenna element, and

wrapping said at least one flexible antenna element in a helical form to produce at least one flexible helical antenna element.

16. A method for aiming a helical antenna comprising at least one flexible helical element while compensating for frequency scanning effects, comprising the steps of:

adjusting the pitch of said at least one flexible helical element to a first predetermined lower limit representing a first predetermined lower elevation,

adjusting the pitch of said at least one flexible helical element from said first predetermined lower limit to a predetermined higher limit representing a predetermined higher elevation,

measuring a first signal strength of a first signal received by said helical antenna during the second adjusting step,

adjusting the pitch of said at least one flexible helical element from said predetermined higher limit towards a second predetermined lower limit representing a second predetermined lower elevation,

measuring a second signal strength of a second signal received by said helical antenna during the third adjusting step,

generating an output signal indicative of the event when the second signal strength changes to a predetermined value less than a predetermined maximum signal value.

17. A method of manufacturing a helical antenna, comprising the steps of:

etching at least one conductive trace from a sheet of conductor bonded to a flexible film;

cutting said flexible film to a size substantially the same as said at least one conductive trace to produce at least one flexible antenna element; and

wrapping said at least one flexible antenna element in a helical form about a form of a predetermined diameter, to produce at least one flexible helical antenna element.

18. A method of claim 17, further comprising the steps of:

forming a power combining circuit on said flexible film, said power combining circuit being coupled to one end of said at least one flexible antenna element; and

wrapping said power combining circuit in a tubular form about a form of a predetermined diameter, prior to wrapping said at least one flexible antenna element in a helical form.

19. The method of claim 18, further comprising the steps of:

sliding said power combining circuit wrapped in tubular form, over a tube shaped substrate; and

sliding a tube shaped substrate over said power combining circuit wrapped in tubular form.

20. The method of claim 19, further comprising the steps of:

sliding said tube shaped substrate over a tube shaped ground element;

securing said tube shaped ground element to a base for mounting said antenna;

securing one end of a tube shaped support tube to said base; and

coupling an other end of said at least one flexible helical antenna element to said an other end of said tube shaped support to produce an antenna assembly.

21. The method of claim 20, further comprising the step of securing a radome to cover said antenna assembly.

22. The method of claim 20, wherein said coupling step further comprises the steps of:

securing said other end of said at least one flexible helical element to an adjustment means for adjusting the axial pitch of said helical antenna; and

securing said adjustment means to said tubular support element.

23. A method of manufacturing a helical antenna comprising the steps of:

cutting a section of flexible twin conductor antenna lead to a predetermined length;

wrapping said cut section of flexible twin antenna lead in a helix shape about a form of predetermined diameter, to produce a wrapped lead; and

heating said wrapped lead to produce a thermoformed lead.

24. A method of manufacturing a helical antenna comprising the steps of:

etching at least one conductive trace from a sheet of conductor bonded to a flexible film;

cutting said flexible film to produce at least one flexible antenna element; and

wrapping said at least one flexible antenna element in a helical form about a form of predetermined diameter, to produce at least one flexible helical antenna element.

* * * * *

US005635945A

United States Patent [19]

McConnell et al.

[11] Patent Number: 5,635,945

[45] Date of Patent: Jun. 3, 1997

[54] QUADRIFILAR HELIX ANTENNA

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[73] Assignee: Magellan Corporation, San Dimas, Calif.

[21] Appl. No.: 445,881

[22] Filed: May 12, 1995

[51] Int. Cl.[6] H01Q 1/36; H01Q 1/38

[52] U.S. Cl. 343/895; 343/860

[58] Field of Search .... 343/895, 700 MS, 343/893, 860, 862, 863, 865, 853, 850, 859; H01Q 1/36, 1/38

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Primary Examiner—Hoanganh T. Le

Attorney, Agent, or Firm—Philip T. Virga

[57] ABSTRACT

A quadrifilar helix antenna for use in satellite communications comprises four conductive elements arranged to define two separate helically twisted loops, one slightly differing in electrical length than the other, to define a cylinder of constant radius supported by itself or by a cylindrical non-conductive substrate. The two separate helically twisted loops are connected to each other in such a way as to constitute the impedance matching, electrical phasing, coupling and power distribution for the antenna. In place of a conventional balun, the antenna is fed at a tap point on one of the conductive elements determined by an impedance matching network which connects the antenna to a transmission line. The matching network can be built with distributed or lumped electrical elements and can be incorporated into the design of the antenna.

20 Claims, 5 Drawing Sheets

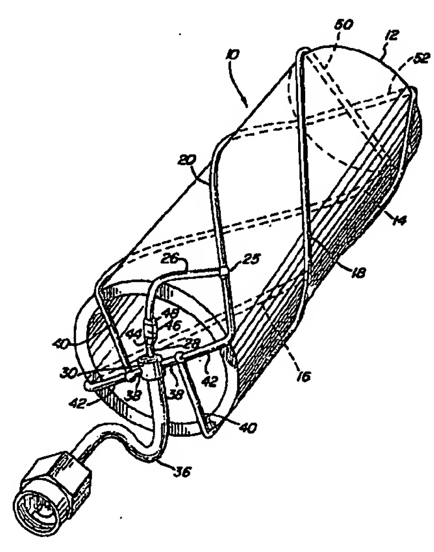


FIG. 1

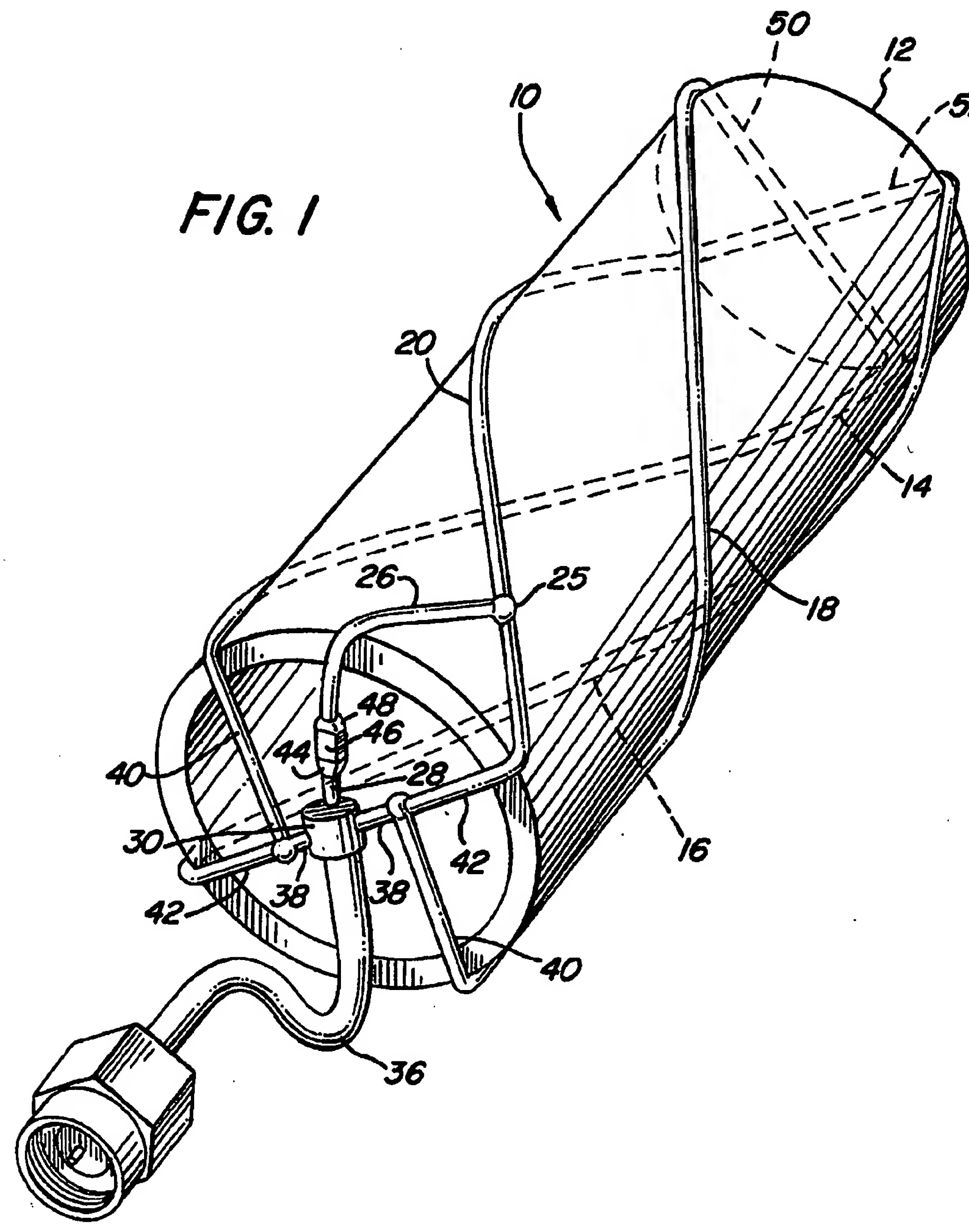


FIG. 2

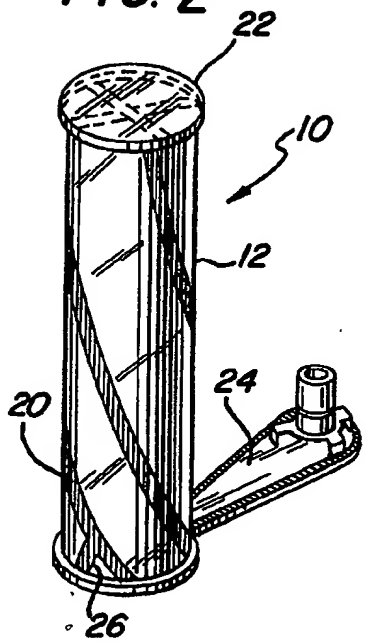


FIG. 3

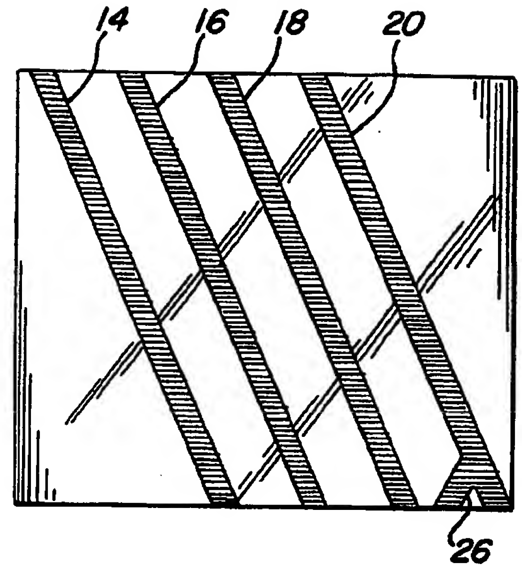


FIG. 4

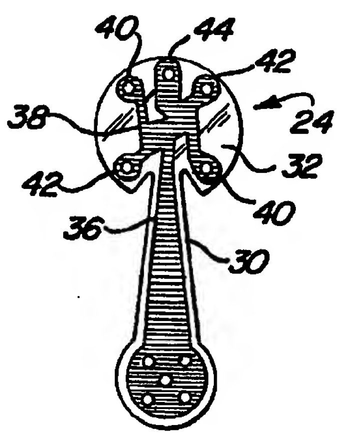


FIG. 5

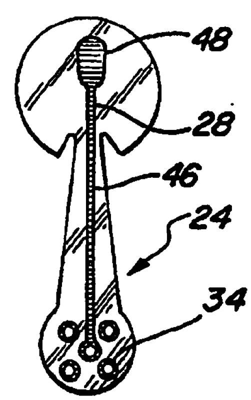


FIG. 6

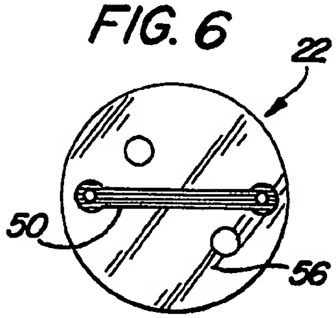
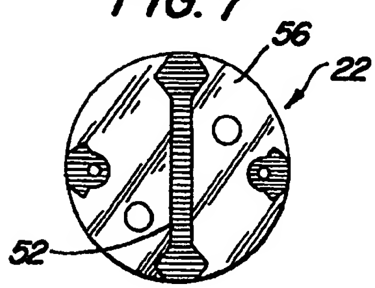


FIG. 7



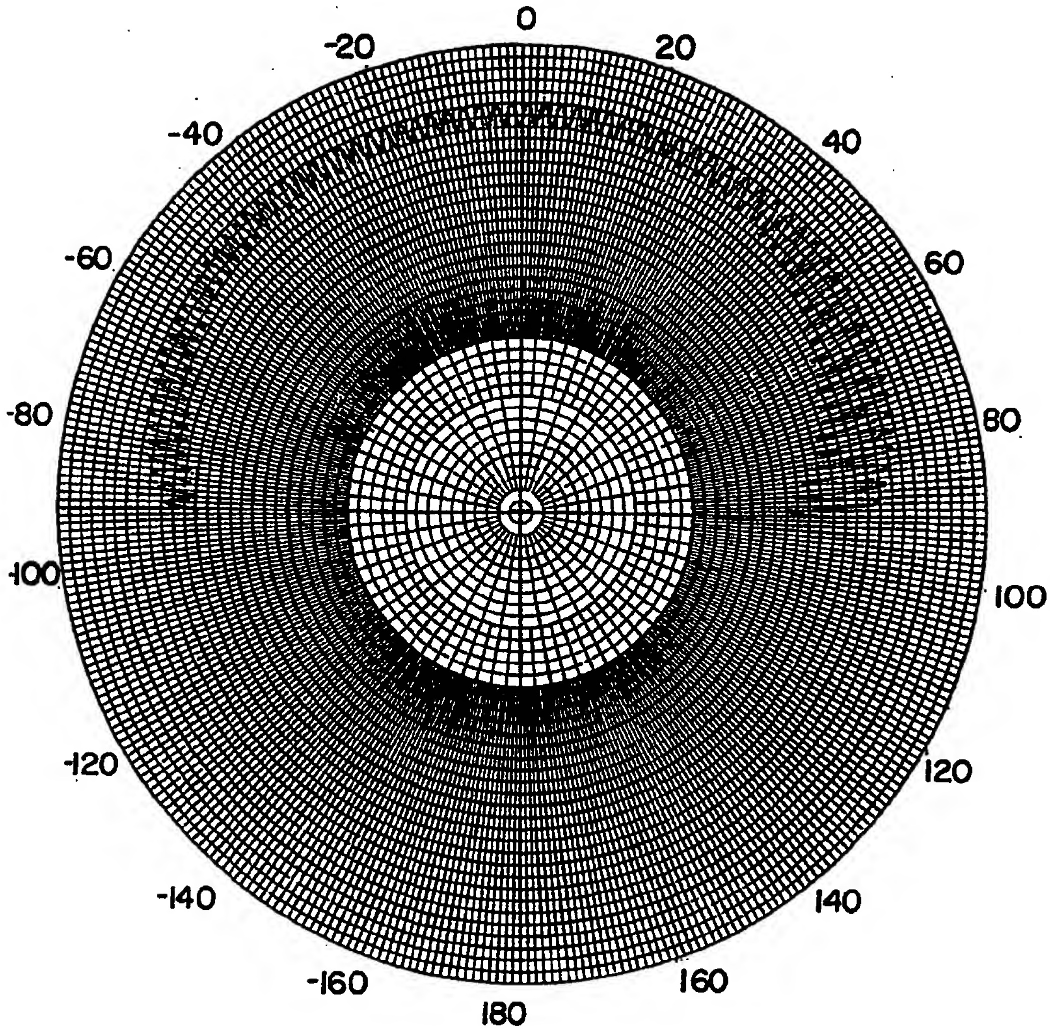


FIG. 8

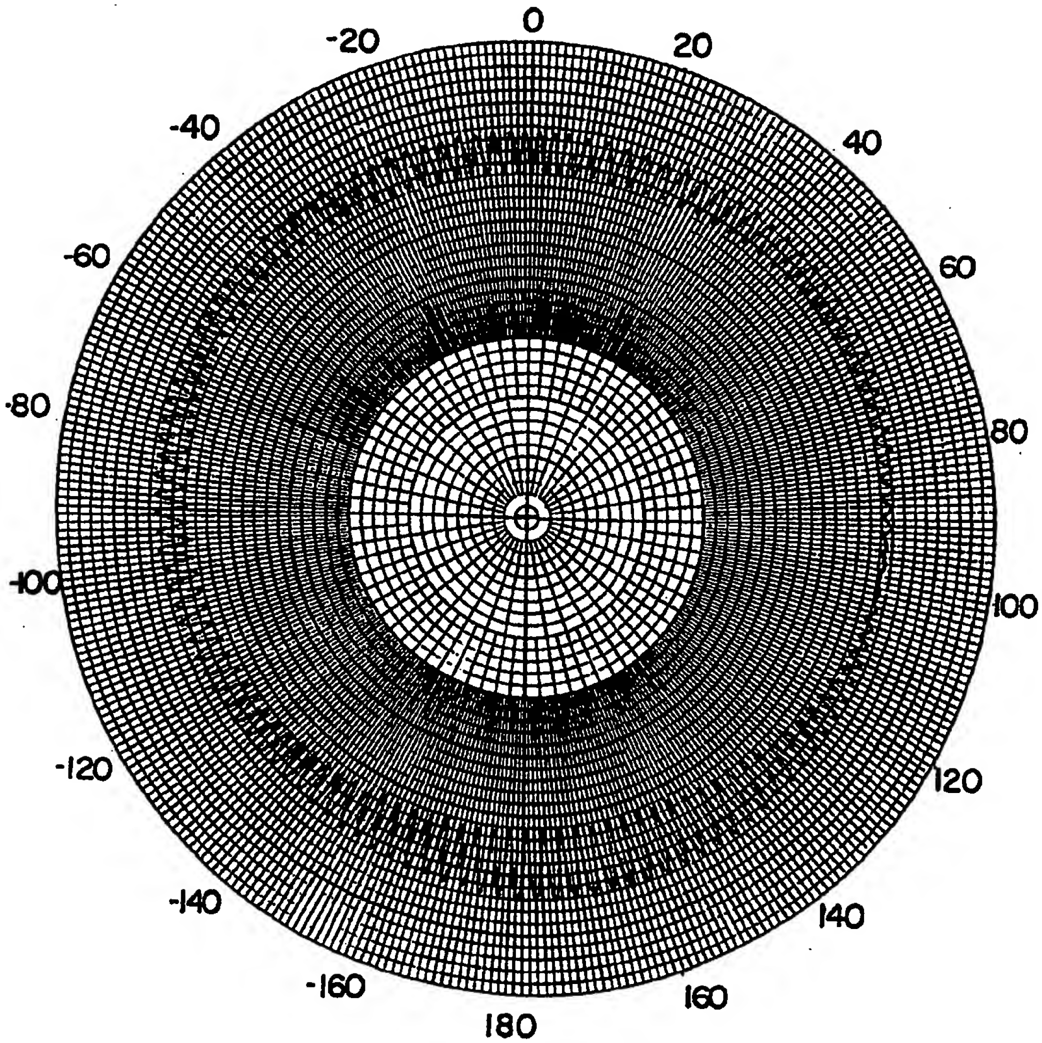


FIG. 9

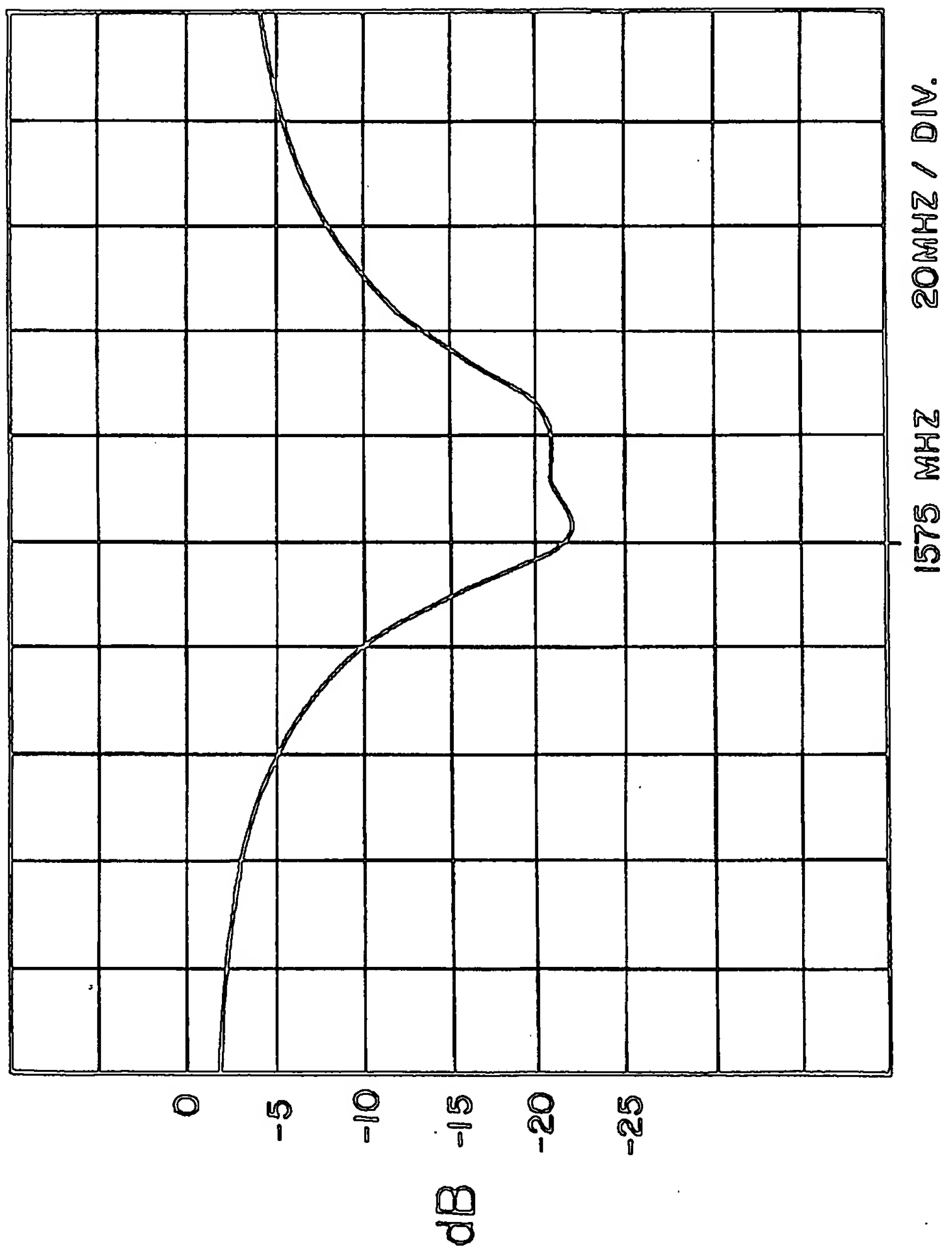


FIG. 10

QUADRIFILAR HELIX ANTENNA

BACKGROUND OF THE INVENTION

This invention generally relates to quadrifilar helix antennas used for radiating or receiving circularly polarized waves. More particularly, this invention relates to an improved feed system for coupling signals of equal magnitude and 90 degrees out of phase to one end of the antenna.

It is well known that helical antennas comprising a plurality of resonant elements arranged around a common axis are particularly useful in ground links with orbiting satellites or in mobile/relay ground links with geosynchronous satellites. Due to the arrangement of the helical elements, the antenna exhibits a dome-shaped spatial response pattern and polarization for receiving signals from satellites. This type of antenna is disclosed in "Multielement, Fractional Turn Helices" by C. C. Kilgus in IEEE Transactions on Antennas Propagation, July 1968, pages 499 and 500. This paper teaches, in particular, that a quadrifilar helix antenna can exhibit a cardioid characteristic in an axial plane and be sensitive to circularly polarized emissions.

One type of prior art helical antenna comprises two bifilar helices arranged in phase quadrature and coupled to an axially located coaxial feeder via a split tube balun for impedance matching. While antennas based on this prior design are widely used because of the particular response pattern, they have the disadvantage that they are extremely difficult to adjust in order to achieve phase quadrature and impedance matching, due to their sensitivity to small variations in element length and other variables, and that the split tube balun is difficult to construct. As a result, their manufacture is a very skilled and expensive process.

Therefore, there is a need for a quadrifilar helix antenna having a predetermined input impedance which could be manufactured on a production basis without the need for adjustment and costly individual tuning. Further, there is a need to provide a quadrifilar helix antenna having a simplified feed arrangement that avoids the complexities of conventional folded, stepped or split shield baluns.

The subject invention herein solves all of these problems in a new and unique manner which has not been part of the art previously. Some related patents are described below:

U.S. Pat. No. 5,191,352 issued to S. Branson on Mar. 2, 1993

This patent is directed to a quadrifilar antenna comprising four helical wire elements shaped and arranged so as to define a cylindrical envelope. The helical wires are mounted at their opposite ends by first and second printed circuit boards having coupling elements in the form of plated conductors which connect the helical wires to a feeder or semi-rigid coaxial cable on the first board, and with each other on the second board. The conductor tracks are such that the effective length of one pair of helical wires and associated impedance elements is greater than that of the other pair of helical wires, so that phase quadrature is obtained between the two pairs.

U.S. Pat. No. 4,008,479 issued to V. C. Smith on Feb. 15, 1977

This patent is directed to a dual-frequency circularly polarized antenna. The antenna comprises a longitudinal cylindrical non-conductive member supported at its top by four conductors each extending transversely from a center coaxial line. Two sets of the antenna conductors are attached to the non-conducting cylinder in a configuration of equally longitudinally spaced spirals. The two sets of conductors are conductively connected by pins such that one set corresponds to a half wavelength at one frequency and the other set corresponds to a half wavelength at another frequency.

U.S. Pat. No. 3,623,113 issued to I. M. Falgen on Nov. 23, 1971

This patent is directed to a tunable helical monopole antenna. The tunable helical monopole antenna comprises a winding having both an upper portion and a lower portion which are symmetrically substantially identical to each other. Connected to each end of the winding halves are cylindrical terminal dipole elements and connected to these terminal elements are shorting fingers. By synchronously moving the shorting fingers, the respective helical windings are effectively shorten or lengthen for tuning purposes.

U.S. Pat. No. 5,255,005 issued to C. Terret et al. on Oct. 19, 1993

This patent is directed to a dual layer resonant quadrifilar helix antenna. The antenna comprises a quadrifilar helix formed by first and second bifilar helices positioned orthogonally and excited in phase quadrature. Additionally, a second quadrifilar helix is coaxially and electromagnetically coupled to a first quadrifilar helix.

U.S. Pat. No, 4,148,030 issued to P. Foldes on Apr. 3, 1979

This patent is directed to a combination helical antenna comprising a plurality of tuned helical antennas which are coaxially wound upon a hollow cylinder, whereby the antennas are collocated. The antenna further comprises a printed circuit assembly having thin metal dipoles of the type used in a microwave strip line. The thin metal dipoles are resonating elements that are coupled to each other in a manner similar to end-fire elements of a microstrip filter.

While the basic concepts presented in the aforementioned patents are desirable, the apparatus employed by each to produce a quadrifilar helix antenna are mechanically far too complicated to render them as an inexpensive means of achieving an antenna having a predetermined input impedance which could be manufactured on a production basis without the need for adjustment and costly individual tuning and still present desired radiation characteristics during operation.

SUMMARY OF THE INVENTION

A quadrifilar helix antenna for use in satellite communications comprises four conductive elements arranged to define two separate helically twisted loops, one slightly differing in electrical length than the other, to define a cylinder of constant radius supported by itself or by a cylindrical non-conductive substrate. The two separate helically twisted loops are connected to each other in such a way as to constitute the impedance matching, electrical phasing, coupling and power distribution for the antenna. In place of a conventional balun, the antenna is fed at a tap point on one of the conductive elements determined by an impedance matching network which connects the antenna to a transmission line. The matching network can be built with distributed or lumped electrical elements and can be incorporated into the design of the antenna.

Therefore, it is an object of the present invention to provide a simple matching network where the inductance of the conductor leading to the tap point is tuned out by a series capacitor before connecting to the transmission line used to transfer radio frequency signals to and from the antenna.

An object of the present invention is to provide a quadrifilar antenna formed by two bifilar helices where the coupling between the two helices is provided by a shared common current path.

A further object of the present invention is to have a quadrifilar antenna which has a simple feed method that

does not require the use of conventional folded, stepped or split shield baluns.

Another object of the present invention is to provide a quadrifilar antenna formed by printed circuit boards which can be relatively accurately formed with predetermined shapes and dimensions, such that relatively little, if any, adjustment is required to obtain an antenna having the required electrical characteristics.

Yet, still another object of the present invention is to have a quadrifilar antenna which can be mass-produced to precise dimensions with high reproducibility of electromagnetic characteristics.

Still, yet another object of the present invention is to provide a quadrifilar antenna which is especially simple in construction, particularly light weight and compact in design.

A further object of the present invention is to provide a low cost antenna having a quasi-hemispherical radiation pattern of the type formed by two bifilar helices used in ground and orbital satellite telecommunication links or in mobile relay telecommunication links with geosynchronous satellites.

Accordingly, it is an object of the present invention to provide an effective, yet inexpensive and relatively mechanically unsophisticated quadrifilar antenna, which is rugged yet lightweight, easily carried and used.

BRIEF DESCRIPTION OF THE DRAWINGS

The above, as well as other, advantages of the present invention will become readily apparent to those skilled in the art from the following detailed descriptions of the preferred embodiment when considered in light of the accompanying drawings in which:

FIG. 1 is a perspective view of a quadrifilar helix antenna in accordance with the present invention;

FIG. 2 is a perspective view of one preferred embodiment of the quadrifilar helix antenna in accordance with the present invention;

FIG. 3 is plan view of the conductive elements shown in FIG. 2;

FIG. 4 is a top plan view of a one side of a first printed circuit board of the antenna of the present invention;

FIG. 5 is a top plan view of a second side of the printed circuit board shown in FIG. 4;

FIG. 6 is a top plan view of one side of a second printed circuit board of the antenna of the present invention;

FIG. 7 is a top plan view of a second side of the printed circuit board shown in FIG. 6; and

FIGS. 8, 9, 10 respectively represent the radiation pattern and value of VSWR of an antenna built in accordance with the teachings of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings wherein like reference numerals refer to like and corresponding parts throughout, the quadrifilar antenna in accordance with the present invention is generally indicated by numeral 10. Referring to FIGURE the quadrifilar antenna 10 comprises a generally elongated non-conducting cylindrical support tube 12 having four conductive elements 14, 16, 18 and 20 supported on an outer surface of tube 12 so as to make the antenna 10 right-hand or left-hand circularly polarized. Although not shown, it should be envisioned that the elements 14, 16, 18 and 20 could be self-supporting without tube 12 by the use of rigid wire or could be arranged against the inner surface of tube 12.

Referring once again to FIG. 1, elements 14 and 18 are cross connected by shorting conductor 50, and elements 16 and 20 are cross connected by shorting conductor 52. A first helix is thus formed by elements 14 and 18, conductor 50 and equal conductors 40 which are slightly longer than a second helix formed by elements 16 and 20, conductor 52 and equal conductors 42. Therefore, the first and second helices have two different electrical lengths translating into two different resonant frequencies which are chosen by design to result in an electrically 90° phase difference between the currents induced in each helix loop thus maintaining phase quadrature. The common section 38 shared by each helix loop provides the coupling from the driven helix formed by elements 16 and 20, conductor 52 and equal conductor 42 to the other helix formed by elements 14 and 18, conductor 50 and equal conductor 40.

Turning once again to FIG. 1, a coaxial transmission line 36 has its inner conductor 28 connected at one end 44 of a capacitor 46 whose other end 48 connects through a conductor 26 to a tap point 25 on element 20 to effectively impedance match antenna 10 without the use of a conventional balun. The placement and value of capacitor 46 and length and tap point of conductor 26 are predetermined from the desired input impedance presented by transmission line 36. Although transmission line 36 is shown as coaxial, it may be any variety of transmission lines used to carry radio frequency signals. Therefore, the capacitor 46 is used to tune out the inductance of conductor 26 at the antenna frequency. An outer conductor 30 of transmission line 36 connects to the midpoint of common conductor section 38. The shape of the antenna 10 may be cylindrically round or square or may be tapered over its length without altering the intent of the invention.

It is understood by those familiar with the art that any method of feeding the antenna 10 with a variety of unbalanced transmission lines in addition to coaxial, such as microstrip or strip line can be accomplished by connecting the signal line to the capacitor 46 at capacitor end 44 and the ground or signal return side to the midpoint of shared common segment

Altough not shown, it may be envisioned that the antenna 10 may be fed with a balanced transmission line in a differential fashion as follows: A duplicate capacitor 46 and connecting conductor 26 as shown in FIG. 1, are connected to conductive element 20 and added in addition to those shown in a like and identical manner to conductive element 16 at a tap point 25 identical to that as shown for element 20. Each wire of the balanced transmission line would than connect individually and separately to each of the ends 44 of capacitors 46.

It is also understood by those skilled in the art, that a transmission line is a common and practical way of transferring radio frequency electrical signals between circuits and antennae and is used herein as an example of how the invention can be utilized. Thus the invention described here could be placed very near to nearby circuits or on printed circuit boards directly where the coupling of signals to the antenna can be accomplished without the need for a conventional transmission line.

Referring now to the drawings, and more particularly to FIG. 2, another preferred embodiment of the quadrifilar antenna 10 comprises a generally elongated longitudinal cylindrical substrate 12 having the four conductive elements

14, 16, 18 and 20 supported on its outer surface and having mounted at opposite ends two printed circuit boards 22 and 24. As shown in FIG. 2, the conductive elements 14, 16, 18 and 20 respectively, are arranged helically around the outer surface of the substrate 12 so as to make the antenna 10 right-hand circularly polarized. Although not shown, it should be envisioned that the antenna 10 could similarly be left-hand circularly polarized.

In the preferred embodiment, the cylindrical substrate 12 is made from a non-conductive material such as glass, fiberglass or the like, having a dielectric constant that corresponds to the width, length and material of the conductive elements 14, 16, 18 and 20, respectively. Using higher dielectric materials can result in significant shortening of the phsyical antenna structure. The cylindrical structure 12 can be formed as a tube or a flat structure rolled into a tubular shape and may have a cross section which is either circular or square. However, it should be well understood that the substrate or material can be varied without deviating from the teachings of the subject invention. The conductive elements 14, 16, 18 and 20, respectively, may be made from copper, silver or like metals and are metal plated onto the substrate 12 by any type of coating technique known in the metallic plating arts.

Turning now to FIG. 3, the conductive elements 14, 16, 18 and 20, respectively, are shown in a plane in order to further distinguish certain characteristics unique to the subject invention. As shown in FIGS. 2 and 3, the conductive elements 14, 16, 18 and 20, respectively, are parallel and substantially equally transversely spaced from each other when plated onto the substrate 12. However, in place of a conventional balun, a feed line 26 is supported on the substrate 12 and is electrically connected to one of the conductive bands 20 at one end and is electrically connected to the printed circuit board 24 at the other end, as will be more fully described below. The location of the feed line 26 is predetermined from the desired input impedance and results in the antenna 10 being manufactured on a production basis without the need for adjustment and costly individual tuning by avoiding the complexities of conventional folded, stepped or split shield baluns.

Referring now to FIGS. 4 and 5, there is shown a first side 32 and second side 34 of the printed circuit board 24, which is used to perform both the power distribution and impedance matching for the antenna 10. The printed circuit board 24 comprises microstrip line 28 over conducting ground plane 30 formed on each side of the board 24, wherein the microstrip structure of 28 and 30, respectively, are electrically coupled to each other to form a microstrip transmission line 36 which serves the same purpose as transmission line 36 in FIG. 1. Turning now to FIG. 4, the ground plane 30, on the first side 32 of the board 24 comprising transmission line 36 terminates into the midsection of a generally rectangular portion 38, the common section coupling the two helices, centered on the board 24. The rectangular portion 38 has a first set 40 and a second set 42 of connecting lines, each set of connecting lines 40 and 42, being electrically connected to a respective one of the conducting elements 14, 16, 18 and 20, serving the same purpose as described in FIG. 1. For electrical characteristic purposes, such as frequency bandwidth, the first set 40 of the connecting lines have a different electrical length, translating into two different resonant frequencies, than the second set 42 of connecting lines, and is a matter of design choice. Even though in the preferred embodiment, the connecting lines are shown as straight, it may be envisioned that the connecting lines may also meander to obtain longer electrical lengths as may the conductors 14, 16, 18 and 20, respectively.

As shown in FIG. 4, on the first side 32 of the board 24 is formed a first capacitive element 44 separated from the rectangular portion 38 and the first set 40 and second set 42 of connecting lines. Referring now to FIG. 5, on the second side 34 of the board 24 is a microstrip line 28 which terminates into a second capacitive element 48. Elements 44 and 48 on each side of board 24 form a parallel plate capacitor whose function is the same as capacitor 46 in FIG. 1. As shown in FIGS. 4 and 5, the transmission line 36 inwardly tapers to connect to the rectangular portion 38 and second capacitive element 48 on the second side 34 of the board 24, wherein the transmission line 36 is tapered solely for mechanical reasons for bending the flexible printed circuit board 24 away from the conductive elements 14, 16, 18 and 20, respectively, and further does not interfere with the antenna radiation pattern. Typically, in the preferred embodiment the transmission line 36 will have an impedance of 50 ohms allowing the antenna 10 to be fed by a BNC connector or coaxial connector.

Referring now to FIGS. 3 through 5, as mentioned above, the feed line 26 supported by the substrate 12 is electrically connected to the conductive band 20 at the tap point 25 and is electrically connected to the first capacitive element 44 at the other end. The feed line 26 has a predetermined shape and position to impedance match the antenna 10 in association with the first capacitive element 44 which electrically couples to the second capacitive element 48 wherein the first and second capacitive elements, 44 and 48 respectively, have predetermined dimensions for matching out the inductance of the feed line

Turning now to FIGS. 6 and 7, the printed circuit board 22 comprises a first shorting line 50 formed on one side 54 of the board 22 and a second shorting line 52, oppositely formed on the other side 56. The first shorting line 50 is connected to a first set of two of the oppositely disposed conductive elements 14 and 18, on the outer surface of the substrate 12, wherein the second shorting line 52 is similarly connected to the second set of oppositely disposed conductive elements 16 and 20, also located on the outer surface of the substrate 12. All the electrical connections from the conducting elements 14, 16, 18 and 20, respectively, to the conductive elements on circuit board 22 and 24 may be accomplished by soldering or other electrical attachment means known in the art.

FIG. 8 illustrates the radiation pattern of an antenna built in accordance with the present invention, obtained in the elevational plane at an approximate frequency of 1575 Mhz. A seen by the pattern, the axial ratio is 1.8 db at zenith, and the maximum circular polarized gain is 2.1 dBic. FIG. 9 illustrates the 80 degree off zenith conic pattern of the same antenna, wherein the maximum gain is shown at 130 degrees having an axial ratio of 2.8 dB and a circular polarized gain of 3.3 dBic. Lastly, FIG. 10 illustrates the impedance and return loss for this antenna with a VSWR of 1.15:1. The above data indicates that the antenna of the present invention performs comparably with conventionally designed quadrifilars.

Furthermore, since the antenna is practically matched at 50 ohms around the two resonance frequencies, the feed line in association with the printed circuit technology does not necessitate any specific assembly for additional matching. This frees the antenna from the drawbacks of conventional quadrifilar antenna designs.

There has been described and illustrated herein, an improved quadrifilar antenna formed by printed circuit boards which can be relatively accurately formed and mass

produced with predetermined shapes and dimensions, such that relatively little, if any, adjustment is required to obtain an antenna having high reproducibility of electromagnetic characteristics.

While particular embodiments of the invention have been described, it is not intended that the invention be limited exactly thereto, as it is intended that the invention be as broad in scope as the art will permit. The foregoing description and drawings will suggest other embodiments and variations within the scope of the claims to those skilled in the art, all of which are intended to be included in the spirit of the invention as herein set forth.

What is claimed is:

1. An antenna comprising:

a plurality of conductive elements, said plurality of conductive elements defining a plurality of helically twisted loops, said helically twisted loops each having a different electrical length and electrically connected to each other through a shared common segment; and an unbalanced transmission line having a first and a second conductor, said first conductor connected to a first end of a capacitor, said capacitor having a second end connected through a conductor to a tap point on at least one of said conductive elements and said second conductor connected to a midpoint of a common conductor section for performing impedance matching, electrical phasing, coupling and power distribution of said antenna.

2. An antenna according to claim 1, wherein said plurality of conductive elements includes four conductive elements arranged to define a first and second separate helically twisted loops, said first helically twisted loop differing in electrical length than said second helically twisted loop, said first and second helically twisted loops defining a cylinder of constant radius.

3. An antenna according to claim 2, wherein said plurality of conductive elements defining a plurality of helically twisted loops are supported on an outer surface of a generally elongated longitudinal non-conducting cylindrical substrate.

4. An antenna according to claim 2, wherein said four conductive elements arranged helically along a generally cylindrical longitudinal non-conductive substrate and supported by said substrate having a first printed circuit board for electrically connecting said four conductive elements at a first end of said substrate, said unbalanced transmission line is a second circuit board for electrically connecting said four conductive elements for performing both power distribution and impedance matching of said four conductive elements at a second end of said substrate.

5. An antenna according to claim 4, wherein said second printed circuit board having a first and second side, said first side defining a microstrip line and said second side defining a conducting ground plane, wherein said microstrip line and said ground plane are electrically coupled to each other to form a microstrip transmission line.

6. An antenna according to claim 5, wherein said ground plane on said second side of said second board terminates into a midsection of a generally rectangular portion, said rectangular portion defining a first set and a second set of connecting lines, each said set of said connecting lines being electrically connected to a respective one of said conducting elements wherein said first and said second set of said connecting lines having different electrical lengths thereby producing two different resonant frequencies.

7. An antenna according to claim 6, wherein said second side of said second board defining a first capacitive element separated from said rectangular portion and said second board defines a generally straight line terminating into a second capacitive element, wherein said first and said second capacitive elements form said capacitor.

8. An antenna according to claim 7, wherein said unbalanced transmission line comprises a feed line electrically connected to at least one of said conductive elements at said tap point and electrically connected to said first capacitive element at an opposite end, said feed line having a shape and position to impedance match said antenna, wherein said first capacitive element on said first side of said board electrically couples to said second capacitive element on said second side of said board, said first and said second capacitive element having predetermined dimensions for matching out said feed lines inductance.

9. An antenna according to claim 6, wherein said ground plane on said second side of said board inwardly tapers to said rectangular portion for bending said second printed circuit board away from said conductive elements and preventing interference with antenna radiation patterns.

10. An antenna according to claim 4, wherein said first printed circuit board having a first shorting line formed on one side of said first board and a second shorting line oppositely formed on an opposing side of said first board, said first shorting line being connected to a first set of two oppositely disposed conductive elements on said outer surface of said substrate and said second shorting line being connected to a second set of oppositely disposed conductive elements on said outer surface of said substrate.

11. An antenna according to claim 1, wherein said unbalanced transmission line comprises a coaxial transmission line wherein said first conductor is an inner conductor and said second conductor is an outer conductor.

12. An antenna according to claim 1, wherein said unbalanced transmission line comprises a microstrip transmission line.

13. An antenna comprising:

(a) a generally cylindrical longitudinal non-conductive substrate;

(b) four conductive elements arranged helically to define a cylinder of constant radius longitudinally along said substrate and supported by said substrate;

(c) a first printed circuit board for electrically connecting said conductive elements at a first end of said substrate and a second circuit board for electrically connecting said four conductive elements having a first and second side, said first side connected to a first end of a capacitor, said capacitor having a second end connected through a conductor to a nap point on at least one of said conductive elements and said second side connected to a midpoint of a common conductor section for performing both power distribution and impedance matching of said four conductive elements at a second end of said substrate.

14. An antenna according to claim 13, wherein said second printed circuit board having said first side defining a microstrip line and said second side defining a conducting ground plane, wherein said microstrip line and said ground plane are electrically coupled to each other to form a microstrip transmission line.

15. An antenna according to claim 14, wherein said ground plane on said second side of said second board terminates into a midsection of a generally rectangular portion, said rectangular portion defining a first set and a second set of connecting lines, each said set of said connecting lines being electrically connected to a respective one of said conducting elements wherein said first and said

second set of said connecting lines having different electrical lengths thereby producing two different resonant frequencies.

16. An antenna according to claim 15, wherein said second side of said second board defining a first capacitive element separated from said rectangular portion and said first and said second set of said connecting lines, and said microstrip line on said first side of said second board defines a generally straight line terminating into a second capacitive element, wherein said first and said second capacitive elements form a parallel plate capacitor.

17. Art antenna according to claim 15, wherein said ground plane on said second side of said second board inwardly tapers to said rectangular portion for bending said second printed circuit board away from said conductive elements and preventing interference with antenna radiation patterns.

18. An antenna according to claim 16, wherein said second circuit board comprises a feed line electrically connected to at least one of said conductive elements at said tap point and electrically connected to said first capacitive element at an opposite end, said feed line having a shape and position to impedance match said antenna, wherein said first capacitive element on said first side of said board electrically couples to said second capacitive element on said second side of said board, said first and said second capacitive element having predetermined dimensions for matching out said feed lines inductance.

19. An antenna according to claim 13, wherein said first printed circuit board having a first shorting line formed on one side of said first board and a second shorting line oppositely formed on an opposing side of said board, said first shorting line being connected to a first set of two oppositely disposed conductive elements on said outer surface of said substrate and said second shorting line being connected to a second set of oppositely disposed conductive elements on said outer surface of said substrate.

20. An antenna comprising:

(a) a generally cylindrical longitudinal non-conductive substrate having a first and second end;

(b) four conductive elements arranged helically to define a cylinder of constant radius longitudinally along said substrate and supported by said substrate;

(c) a first printed circuit board having microstrip lines formed on a first and second side of said first board, said microstrip line on said first side comprises a ground plane terminating into a generally rectangular portion, said rectangular portion having a first set and second set of connecting lines, each said connecting line being electrically connected to respective one of said conducting elements on a first end of said substrate, said first set of said connecting lines having different electrical lengths than said second set of said connecting lines;

(d) said first side of said first board having a first capacitive element separated from said rectangular portion and said first and said second set of said connecting lines, said microstrip line on said second side defining a generally straight line terminating into a second capacitive element, said first and said second capacitive elements forming a parallel plate capacitor;

(e) a feed line supported by said substrate and electrically connected to at least one of said conductive elements at a tap point and electrically connected to said first capacitive element at an opposite end, said feed line having a shape and position to impedance match said antenna, wherein said first capacitive element electrically couples to said second capacitive element on said second side of said board, and wherein said first and said second capacitive element having predetermined dimensions for matching out an inductance of said feed line; and

(f) a second printed circuit board having a first shorting line formed on one side of said second board and a second shorting line oppositely formed on an opposing side of said board, said first shorting line being connected to a first set of two oppositely disposed conductive elements on said outer surface of said substrate and said second shorting line being connected to a second set of oppositely disposed conductive elements on said outer surface of said substrate.

* * * * *

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United States Patent [19]

Leisten

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[45] **Date of Patent:** Jan. 12, 1999

[54] **ANTENNA**

[75] Inventor: **Oliver Paul Leisten**, Kingsthorpe, England

[73] Assignee: **SymmetriCom, Inc.**, San Jose, Calif.

[21] Appl. No.: **804,209**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[6] **H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 343/821; 343/859

[58] **Field of Search** .... 343/700 MS, 702, 343/821, 850, 853, 859, 860, 895, 865; 29/600, 601; H01Q 1/24, 1/36, 1/38, 11/08, 21/20

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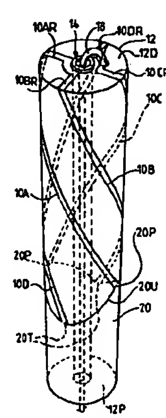
Primary Examiner—Hoanganh T. Le
Assistant Examiner—Tho Phan
Attorney, Agent, or Firm—Mark A. Haynes; Wilson, Sonsini, Goodrich & Rosati

[57] **ABSTRACT**

An antenna for use at frequencies of 200 MHz and upwards has a cylindrical ceramic core with a relative dielectric constant of at least 5, and pairs of helical elements extending from a feed point at one end of the core to the rim of a conductive sleeve adjacent the other end of the core, the sleeve acting as a trap for isolating from ground currents circulating in the helical elements. To yield helical elements of different lengths, the sleeve rim follows a locus which deviates from a plane perpendicular to the core axis in that it describes a zig-zag path. The helical elements form simple helices with approximately balanced radiation resistances.

13 Claims, 1 Drawing Sheet



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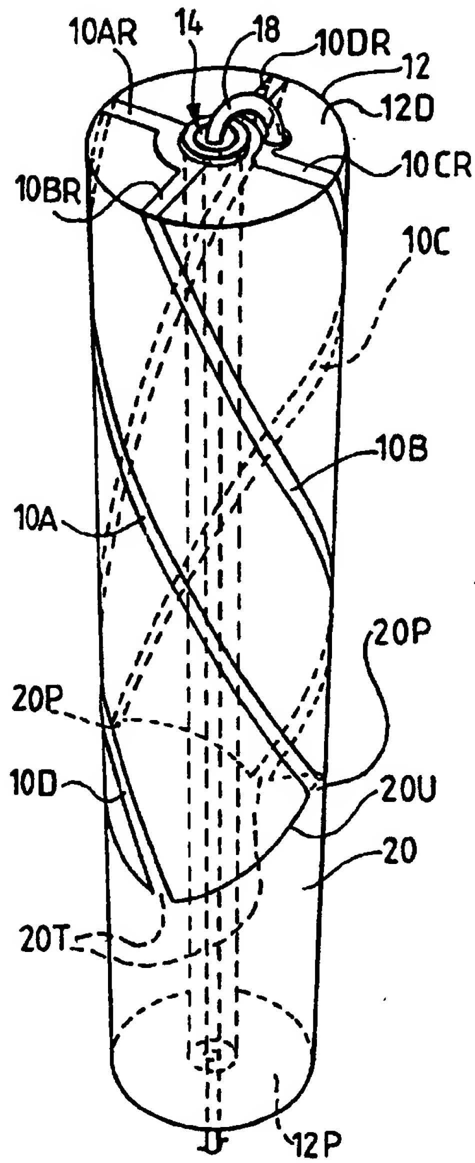
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FIG.1.

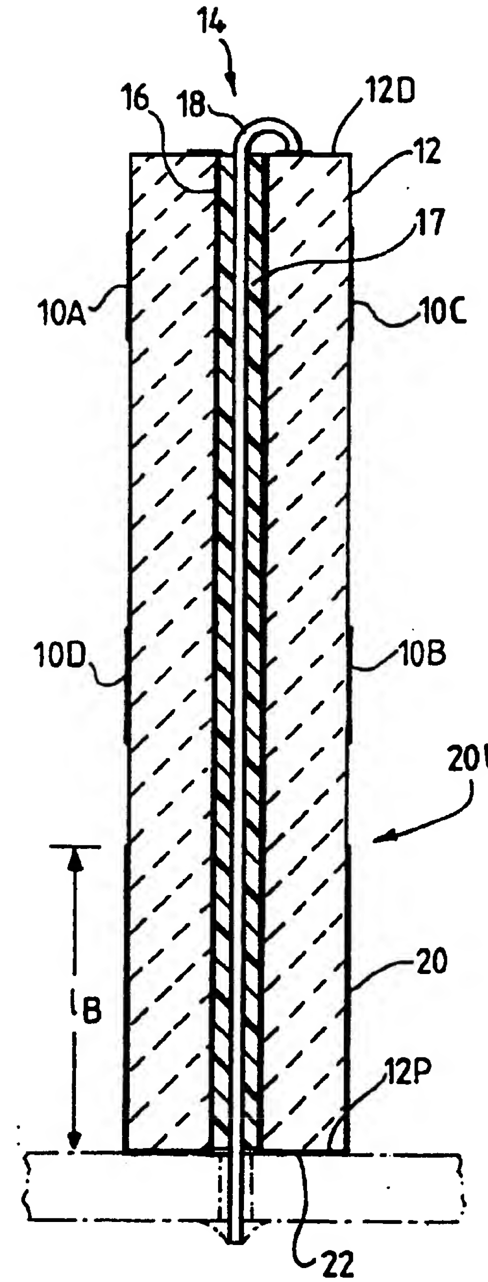
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FIG.2.

ANTENNA

FIELD OF THE INVENTION

This invention relates to an antenna for operation at frequencies in excess of 200 MHz, and particularly but not exclusively to an antenna having helical elements on or adjacent the surface of a dielectric core for receiving circularly polarised signal. Such signals are transmitted by satellites of the Global Positioning System (GPS).

BACKGROUND OF THE INVENTION

Such an antenna is disclosed in our co-pending British Patent Application No. 9517086.6, the entire disclosure of which is incorporated in this present application so as to form part of the subject matter of this application as first filed. The earlier application discloses a quadrifilar antenna having two pairs of diametrically opposed helical antenna elements, the elements of the second pair following respective meandered paths which deviate on either side of a mean helical line on an outer cylindrical surface of the core so that the elements of the second pair are longer than those of the first pair which follow helical paths without deviation. Such variation in the element lengths makes the antenna suitable for transmission or reception of circularly polarised signals.

The applicants have found that such an antenna tends to favour reception of elliptically rather than circularly polarised signals, and it is an object of the present invention to provide for enhanced reception of circularly polarised signals.

SUMMARY OF THE INVENTION

According to this invention, an antenna for operation at frequencies in excess of 200 MHz comprises a substantially cylindrical electrically insulative core of a material having a relative dielectric constant greater than 5, with the material of the core occupying the major part of the volume defined by the core outer surface, a feeder structure extending axially through the core, a trap in the form of a conductive sleeve encircling part of the core and having a ground connection at one edge, and first and second pairs of antenna elements each connected at one end to the feeder structure and at the other end to a linking edge of the sleeve, the antenna elements of the second pair being longer than those of the first pair, wherein the antenna elements of both pairs follow respective longitudinally extending paths, and the said linking edge follows a non-planar path around the core, the antenna elements of the first pair being joined to the linking edge at points which are nearer to the connections of the elements to the feeder structure than are the points at which the antenna elements of the second pair are joined to the linking edge. The longitudinally extending paths are preferably helical paths, each element subtending the same angle of rotation at the core axis, e.g. 180° or a half turn. In this way it is possible to avoid deviations of the longer antenna elements from the respective helical paths, thereby yielding more balanced radiation resistances for the antenna elements and consequent improved performance with circularly polarised signals.

The core may be a cylindrical body which is solid with the exception of a narrow axial passage housing the feeder structure. Preferably, the volume of the solid material of the core is at least 50 percent of the internal volume of the envelope defined by the antenna elements and the sleeve, with the elements lying on an outer cylindrical surface of the core. The elements may comprise metallic conductor tracks bonded to the core outer surface, for example by deposition or by etching of a previously applied metallic coating.

For reasons of physical and electrical stability, the material of the core may be ceramic, e.g. a microwave ceramic material such as a zirconium-titanate-based material, magnesium calcium titanate, barium zirconium tantalate, and barium neodymium titanate, or a combination of these. The preferred relative dielectric constant is upwards of 10 or, indeed, 20, with a figure of 36 being attainable using zirconium-titanate-based material. Such materials have negligible dielectric loss to the extent that the Q of the antenna is governed more by the electrical resistance of the antenna elements than core loss.

A particularly preferred embodiment of the invention has a cylindrical core of solid material with an axial extent at least as great as its outer diameter, and with the diametrical extent of the solid material being at least 50 percent of the outer diameter. Thus, the core may be in the form of a tube having a comparatively narrow axial passage of a diameter at most half the overall diameter of the core. The inner passage may have a conductive lining which forms part of the feeder structure or a screen for the feeder structure, thereby closely defining the radial spacing between the feeder structure and the antenna elements. This helps to achieve good repeatability in manufacture. The helical antenna elements are preferably formed as metallic tracks on the outer surface of the core which are generally co-extensive in the axial direction. Each element is connected to the feeder structure at one of its ends and to the sleeve at its other end, the connections to the feeder structure being made with generally radial conductive elements, and the sleeve being common to all of the helical elements. The trap produces a virtual ground for the antenna elements at the linking edge. The radial elements may be disposed on a distal end surface of the core.

The preferred embodiment has antenna elements with an average electrical length of $\lambda/2$, but alternative embodiments are feasible having electrical lengths of e.g. $\lambda/4$, $3\lambda/4$, λ and other multiples of $\lambda/4$, which produce modified radiation patterns.

Advantageously the helical elements extend proximally from the distal end of the core to the conductive sleeve which extends over part of the length of the core from a connection with the feeder structure at the proximal end of the core. In the case of the feeder structure comprising a coaxial line having an inner conductor and an outer screen conductor, the conductive sleeve is connected at the proximal end of the core to the feeder structure outer screen conductor.

Using the above-described features it is possible to make an antenna which is extremely robust due to its small size and due to the elements being supported on a solid core of rigid material. Such an antenna can be arranged to have a low-horizon omni-directional response with robustness sufficient for use as a replacement for patch antennas in certain applications. Its small size and robustness render it suitable also for unobtrusive vehicle mounting and for use in handheld devices. It is possible in some circumstances even to mount it directly on a printed circuit board.

The longitudinal extent of the antenna elements, i.e. in the axial direction, is generally greater than the average axial length of the conductive sleeve. Typically the average axial length of the antenna element is twice that of the sleeve, and the diameters of the elements and the sleeve are the same and in the range of from 0.15 to 0.25 times the combined length of the antenna elements and the sleeve. Preferably, the

average axial length of the sleeve is not less than 0.35 times the average axial length of the antenna elements. The difference in axial length between the antenna elements of the first pair and those of the second pair is generally less than one half of their average length and preferably in the range of from 0.05 to 0.15 times their average length.

The antenna may be manufactured by forming the antenna core from the dielectric material, and metallising the external surfaces of the core according to a predetermined pattern. Such metallisation may include coating external surfaces of the core with a metallic material and then removing portions of the coating to leave the predetermined pattern, or alternatively a mask may be formed containing a negative of the predetermined pattern, and the metallic material is then deposited on the external surfaces of the core while using the mask to mask portions of the core so that the metallic material is applied according to the pattern. Other methods of depositing a conductive pattern of the required form can be used.

A particularly advantageous method of producing an antenna having a trap or balun sleeve and a plurality of antenna elements forming part of a radiating element structure, comprises the steps of providing a batch of the dielectric material, making from the batch at least one test antenna core, and then forming a balun structure, preferably without any radiating element structure, by metallising on the core a balun sleeve having a predetermined nominal dimension which affects the frequency of resonance of the balun structure. The resonant frequency of this test resonator is then measured and the measured frequency is used to derive an adjusted value of the balun sleeve dimension for obtaining a required balun structure resonant frequency. The same measured frequency can be used to derive at least one dimension for the helical antenna elements to give a required antenna elements frequency characteristic. Antennas manufactured from the same batch of material are then produced with a sleeve and antenna elements having the derived dimensions.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a perspective view of an antenna in accordance with the invention; and

FIG. 2 is a diagrammatic axial cross-section of the antenna.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, a quadrifilar antenna in accordance with the invention has an antenna element structure with four longitudinally extending antenna elements **10A**, **10B**, **10C**, and **10D** formed as metallic conductor tracks on the cylindrical outer surface of a ceramic core **12**. The core has an axial passage **14** with an inner metallic lining **16**, and the passage houses an axial feeder conductor **18**. The inner conductor **18** and the lining **16** in this case form a feeder structure for connecting a feed line to the antenna elements **10A–10D**. The antenna element structure also includes corresponding radial antenna elements **10AR**, **10BR**, **10CR**, **10DR** formed as metallic tracks on a distal end face **12D** of the core **12** connecting ends of the respective longitudinally extending elements **10A–10D** to the feeder structure. The other ends of the antenna elements **10A–10D** are connected to a common virtual ground conductor **20** in the form of a plated sleeve surrounding a proximal end portion of the core **12**. This sleeve **20** is in turn connected to the lining **16** of the axial passage **14** by plating **22** on the proximal end face **12P** of the core **12**.

As will be seen from FIG. **1**, the four longitudinally extending elements **10A–10D** are of different lengths, two of the elements **10B**, **10D** being longer than the other two **10A**, **10C** by virtue of extending nearer the proximal end of the core **12**. The elements of each pair **10A**, **10C**; **10B**, **10D** are diametrically opposite each other on opposite sides of the core axis.

In order to maintain approximately uniform radiation resistance for the helical elements **10A–10D**, each element follows a simple helical path. Since each of the elements **10A–10D** subtends the same angle of rotation at the core axis, here 180° or a half turn, the screw pitch of the long elements **10B**, **10D** is steeper than that of the short elements **10A**, **10C**. The upper linking edge **20U** of the sleeve **20** is of varying height (i.e. varying distance from the proximal end face **12P**) to provide points of connection for the long and short elements respectively. Thus, in this embodiment, the linking edge **2GU** follows a zig-zag path around the core **12**, having two peaks **20P** and two troughs **20T** where it meets the short elements **10A**, **10C** and long elements **10B**, **10D** respectively.

Each pair of longitudinally extending and corresponding radial elements (for example **10A**, **10AR**) constitutes a conductor having a predetermined electrical length. In the present embodiment, it is arranged that the total length of each of the element pairs **10A**, **10AR**; **10C**, **10CR** having the shorter length corresponds to a transmission delay of approximately 135° at the operating wavelength, whereas each of the element pairs **10B**, **10BR**; **10D**, **10DR** produce a longer delay, corresponding to substantially 225°. Thus, the average transmission delay is 180°, equivalent to an electrical length of $\lambda/2$ at the operating wavelength. The differing lengths produce the required phase shift conditions for a quadrifilar helix antenna for circularly polarised signals specified in Kilgus, "Resonant Quadrifilar Helix Design", The Microwave Journal, Dec. 1970, pages 49–54. Two of the element pairs **10C**, **10CR**; **10D**, **10DR** (i.e. one long element pair and one short element pair) are connected at the inner ends of the radial elements **10CR**, **10DR** to the inner conductor **18** of the feeder structure at the distal end of the core **12**, while the radial elements of the other two element pairs **10A**, **10AR**; **10B**, **10BR** are connected to the feeder screen formed by metallic lining **16**. At the distal end of the feeder structure, the signals present on the inner conductor **18** and the feeder screen **16** are approximately balanced so that the antenna elements are connected to an approximately balanced source or load, as will be explained below.

With the left handed sense of the helical paths of the longitudinally extending elements **10A–10D**, the antenna has its highest gain for right hand circularly polarised signals.

If the antenna is to be used instead for left hand circularly polarised signals, the direction of the helices is reversed and the pattern of connection of the radial elements is rotated through 90°. In the case of an antenna suitable for receiving both left hand and right hand circularly polarised signals, the longitudinally extending elements can be arranged to follow paths which are generally parallel to the axis.

The conductive sleeve **20** covers a proximal portion of the antenna core **12**, thereby surrounding the feeder structure **16**, **18**, with the material of the core **12** filling the whole of the space between the sleeve **20** and the metallic lining **16** of the axial passage **14**. The sleeve **20** forms a cylinder having an average axial length l_B as show in FIG. **2** and is connected

to the lining **16** by the plating **22** of the proximal end face **12P** of the core **12**. The combination of the sleeve **20** and plating **22** forms a balun so that signals in the transmission line formed by the feeder structure **16**, **18** are converted between an unbalanced state at the proximal end of the antenna and an approximately balanced state at an axial position generally at the same distance from the proximal end as the upper linking edge **20U** of the sleeve **20**. To achieve this effect, the average sleeve length l_B is such that, in the presence of an underlying core material of relatively high relative dielectric constant, the balun has an average electrical length of $\lambda/4$ at the operating frequency of the antenna. Since the core material of the antenna has a foreshortening effect, and the annular space surrounding the inner conductor **18** is filled with an insulating dielectric material **17** having a relatively small dielectric constant, the feeder structure distally of the sleeve **20** has a short electrical length. Consequently, signals at the distal end of the feeder structure **16**, **18** are at least approximately balanced. (The dielectric constant of the insulation in a semi-rigid cable is typically much lower than that of the ceramic core material referred to above. For example, the relative dielectric constant ϵ_r of PTFE is about 2.2.)

The applicants have found that the variation in length of the sleeve **20** from the mean electrical length of $\lambda/4$ has a comparatively insignificant effect on the performance of the antenna. The trap formed by the sleeve **20** provides an annular path along the linking edge **20U** for currents between the elements **10A–10D**, effectively forming two loops, the first with short elements **10A**, **10C** and the second with the long elements **10B**, **10D**. At quadrifilar resonance current maxima exist at the ends of the elements **10A–10D** and in the linking edge **20U**, and voltage maxima at a level approximately midway between the edge **20U** and the distal end of the antenna. The edge **20U** is effectively isolated from the ground connector at its proximal edge due to the approximate quarter wavelength trap produced by the sleeve **20**.

The antenna has a main resonant frequency of 500 MHz or greater, the resonant frequency being determined by the effective electrical lengths of the antenna elements and, to a lesser degree, by their width. The lengths of the elements, for a given frequency of resonance, are also dependent on the relative dielectric constant of the core material, the dimensions of the antenna being substantially reduced with respect to an air-cored similarly constructed antenna.

The preferred material for the core **12** is zirconium-titanate-based material. This material has the above-mentioned relative dielectric constant of 36 and is noted also for its dimensional and electrical stability with varying temperature. Dielectric loss is negligible. The core may be produced by extrusion or pressing.

The antenna elements **10A–10D**, **10AR–10DR** are metallic conductor tracks bonded to the outer cylindrical and end surfaces of the core **12**, each track being of a width at least four times its thickness over its operative length. The tracks may be formed by initially plating the surfaces of the core **12** with a metallic layer and then selectively etching away the layer to expose the core according to a pattern applied in a photographic layer similar to that used for etching printed circuit boards. Alternatively, the metallic material may be applied by selective deposition or by printing techniques. In all cases, the formation of the tracks as an integral layer on the outside of a dimensionally stable core leads to an antenna having dimensionally stable antenna elements.

With a core material having a substantially higher relative dielectric constant than that of air, e.g. ϵ_r=36, an antenna as described above for L-band GPS reception at 1575 MHz typically has a core diameter of about 5 mm and the longitudinally extending antenna elements **10A–10D** have an average longitudinal extent (i.e. parallel to the central axis) about 16 mm. The long elements **10B**, **10D** are about 1.5 mm longer than the short elements **10A**, **10C**. The width of the elements **10A–10D** is about 0.3 mm At 1575 MHz, the length of the sleeve **22** is typically in the region of 8 mm. Precise dimensions of the antenna elements **10A–10D** can be determined in the design stage on a trial and error basis by undertaking eigenvalue delay measurements until the required phase difference is obtained.

The manner in which the antenna is manufactured is described in the above-mentioned copending application No. 9517086.6 published as GB2292638A on Feb. 28, 1996, and described in U.S. patent application Ser. No. 08/351, 631, filed Dec. 6, 1994 at pages 12 through 16 and 18 through 19 which are incorporated by reference. Alternatively, the methods of manufacture disclosed in U.S. patent application Ser. No. 08/707,947 filed Sep. 10, 1996, at pages 8 through 12 of which are incorporated by reference may also be used.

What is claimed is:

1. An antenna for operation at frequencies in excess of 200 MHz, comprising a substantially cylindrical electrically insulative core of a material having a relative dielectric constant greater than 5, with the material of the core occupying the major part of the volume defined by the core outer surface, a feeder structure extending axially through the core, a trap in the form of a conductive sleeve encircling part of the core and having a ground connection at one edge, and first and second pairs of antenna elements each connected at one end to the feeder structure and at the other end to a linking edge of the sleeve, the antenna elements of the second pair being longer than those of the first pair, wherein the antenna elements of both pairs follow respective longitudinally extending paths, and the said linking edge follows a non-planar path around the core, the antenna elements of the first pair being joined to the linking edge at points which are nearer to the connections of the elements to the feeder structure than are the points at which the antenna elements of the second pair are joined to the linking edge.

2. An antenna according to claim 1, wherein each of the longitudinally extending antenna element follows a respective helical path around the axis of the core, and the angle subtended by the two respective ends of each said antenna element at the core axis is the same in each case.

3. An antenna according to claim **2**, wherein each of the said elements executes a half turn around the core axis, the connections between the elements and the feeder structure lying in a common plane perpendicular to the core axis, and wherein the screw pitch of the elements of the first pair is different from that of the elements of the second pair.

4. An antenna according to claim 1, wherein the linking edge of the trap follows a zig-zag path around the core with the elements of the first and second pair being joined at peaks and troughs respectively of the linking edge.

5. An antenna according to claim 1, wherein the ground connection edge of the trap lies in a plane perpendicular to the core axis and the average axial length of the sleeve forming the trap is at least approximately $\lambda/4$, where λ is the operating wavelength at the interface between air and the dielectric material of the core.

6. An antenna according to claim **1**, which is quadrifilar, having a single first pair and a single second pair of antenna elements.

7. An antenna according to claim **1**, wherein the trap and the antenna elements are integrally formed on the cylindrical outer surface of the core.

8. An antenna according to claim 1, wherein the antenna elements of the first and second pairs are connected to the feeder structure by respective radial elements on a planar end surface of the core, and wherein the ground connection of the trap is formed by a conductive layer formed on the other end surface of the core.

9. An antenna according to claim 8, wherein the feeder structure is a coaxial transmission line, each of the said antenna element pairs having one element connected to an inner conductor of the feeder structure and one element connected to an outer conductor of the feeder structure, and wherein the outer conductor is joined to the said conductive layer.

10. An antenna according to claim 1, wherein the average axial length of the antenna elements is greater than the average axial length of the conductive sleeve.

11. An antenna according to claim 10, wherein the average axial length of the antenna element is, at least approximately, twice the average axial length of the sleeve, and the diameter of the elements and the diameter of the sleeve are the same and in the range of from 0.15 to 0.25 times the combined length of the antenna elements and the sleeve.

12. An antenna according to claim 10, wherein the ratio of the average axial length of the antenna elements to the average axial length of the sleeve is less than or equal to 1:0.35.

13. An antenna according to claim 1, wherein the difference in axial length between the antenna elements of the first pair and those of the second pair is less than one half of their average length.

* * * * *

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United States Patent [19]

O'Neill, Jr.

[11] **Patent Number:** 5,909,196

[45] **Date of Patent:** Jun. 1, 1999

[54] **DUAL FREQUENCY BAND QUADRIFILAR HELIX ANTENNA SYSTEMS AND METHODS**

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[73] Assignee: **Ericsson Inc.**, Research Triangle Park, N.C.

[21] Appl. No.: **08/770,904**

[22] Filed: **Dec. 20, 1996**

[51] **Int. Cl.**[6] **H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 343/853

[58] **Field of Search** 343/895, 850, 343/853, 876, 701; H01Q 1/38, 1/36

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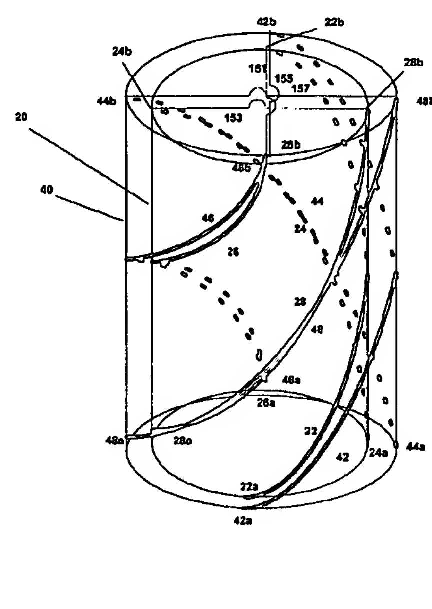
Assistant Examiner—Tho Phan
Attorney, Agent, or Firm—Myers Bigel Sibley & Sajovec

[57] **ABSTRACT**

A quadrifilar helix antenna system capable of providing a positive gain, quasi-hemispherical antenna pattern over widely separate transmit and receive frequency bands. This new antenna system comprises concentrically arranged, but electrically isolated, transmit and receive quadrifilar helix antennas, each of which comprises two bifilar helices arranged orthogonally and excited in phase quadrature. In the preferred embodiment, the antenna elements forming each bifilar helix are short-circuited at their distal ends, and energy is induced from the receive antenna and coupled to the transmit antenna via receive and transmit 90° hybrid couplers which are electrically connected to the bifilar loops of the respective receive and transmit antennas. Also provided are switches or other disconnection means which are used to electrically isolate the transmit antenna during periods when the antenna is receiving a signal and to electrically isolate the receive antenna during periods of transmission. In the preferred embodiments, these disconnecting means are implemented as PIN diodes or radio frequency Gallium arsenide field effect transistor switches.

23 Claims, 4 Drawing Sheets



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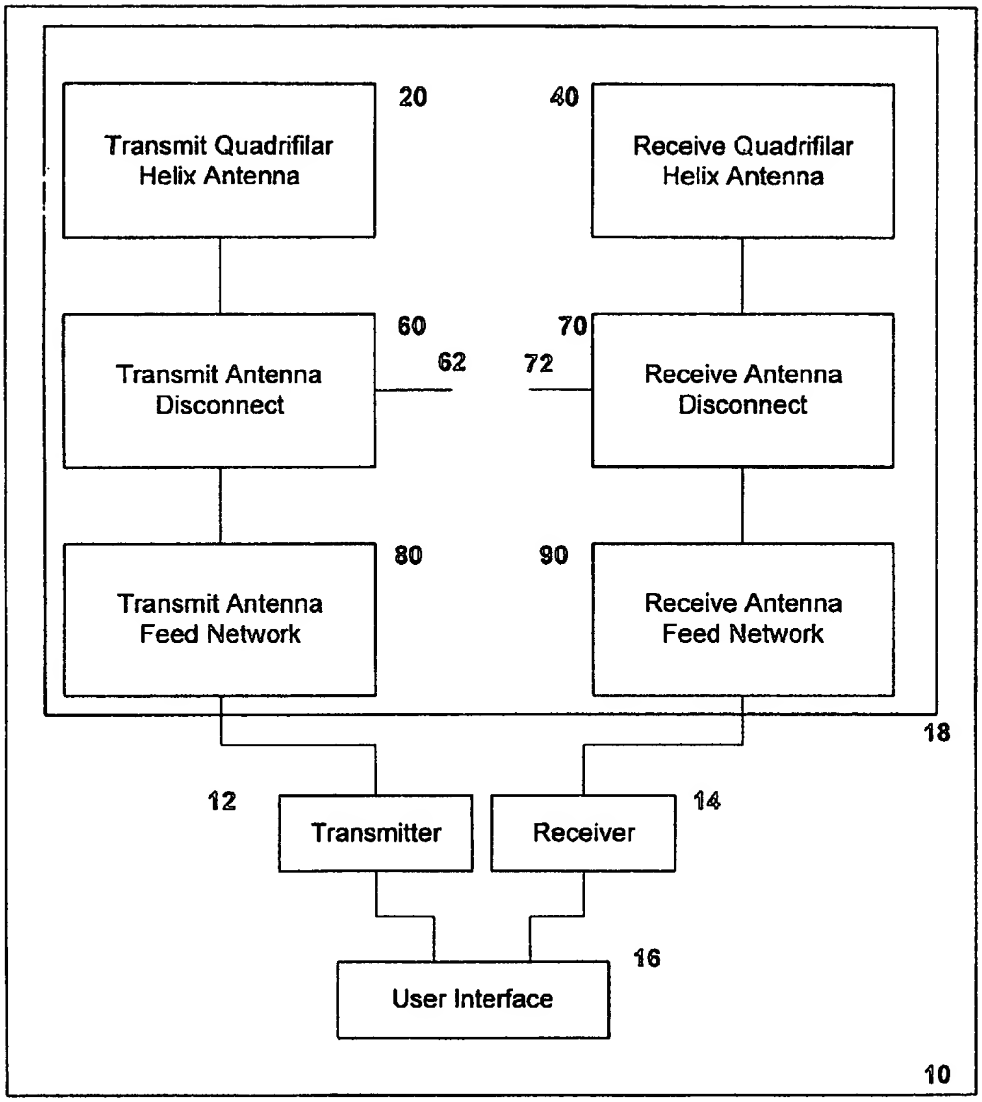
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Receive Quadrifilar Helix Antenna
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70
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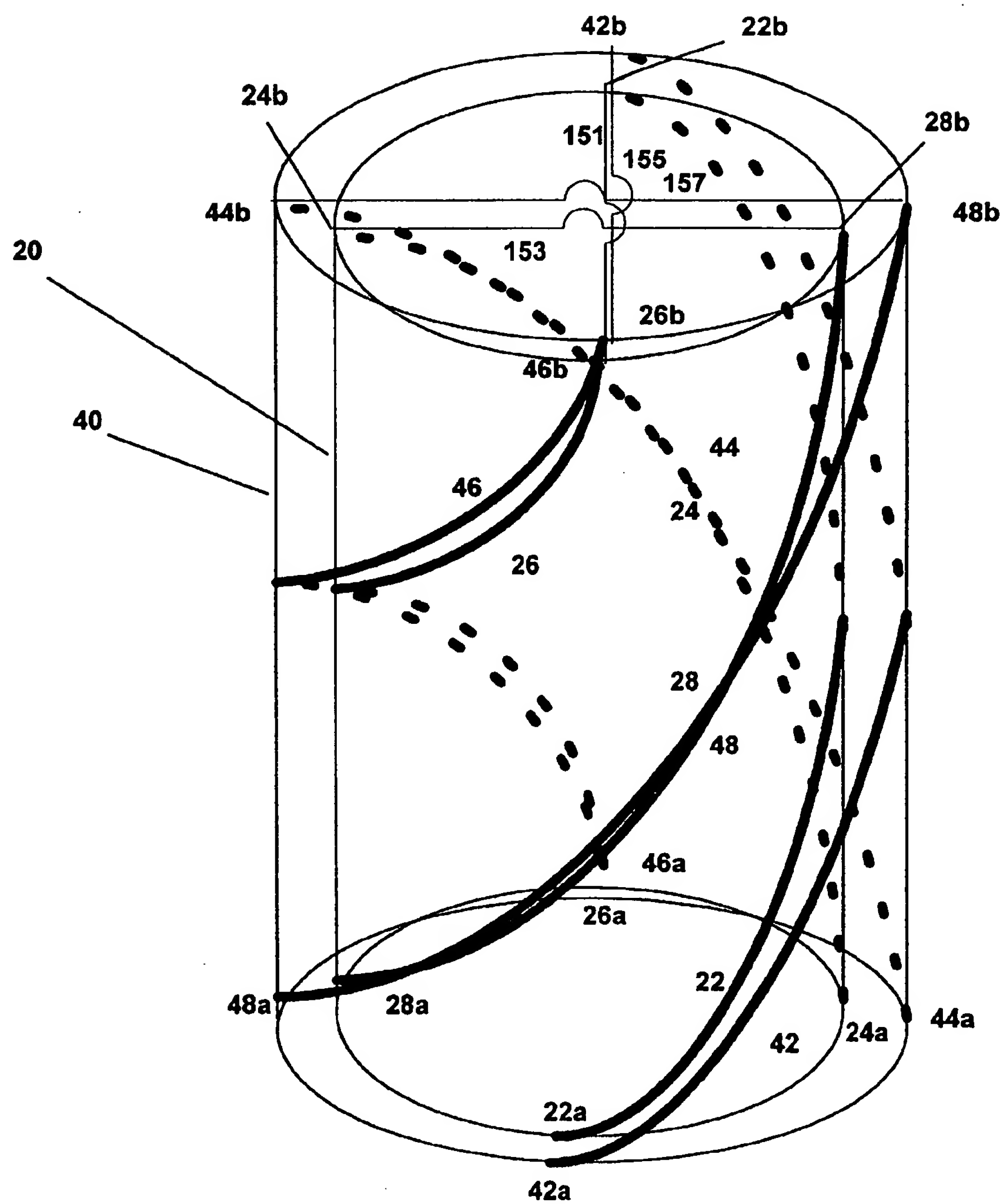
90
Receive Antenna Feed Network
18
12
Transmitter
Receiver
14
User Interface
16
10

Figure 1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26a
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48a
28a
44a
42
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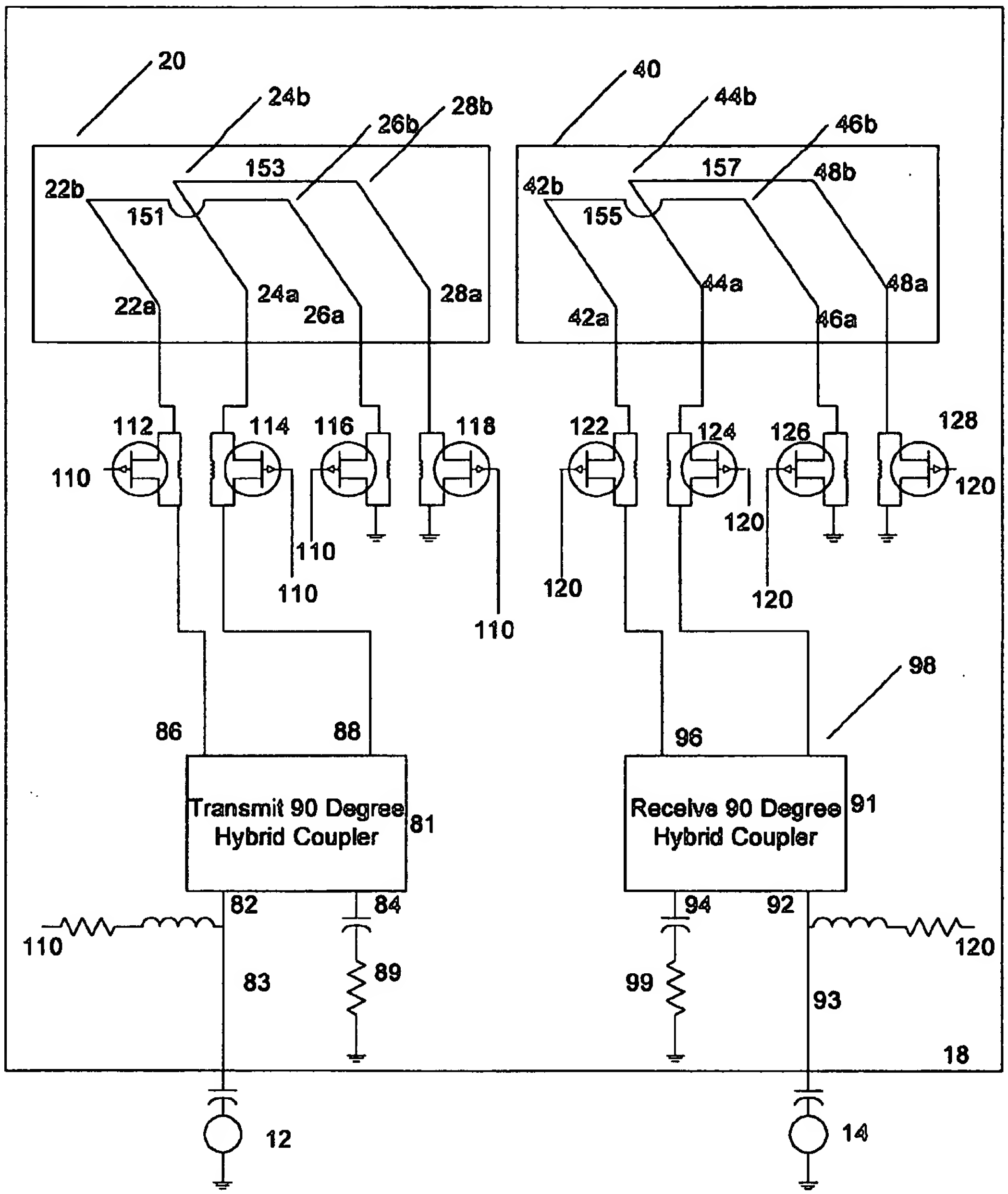
22a
42a

Figure 2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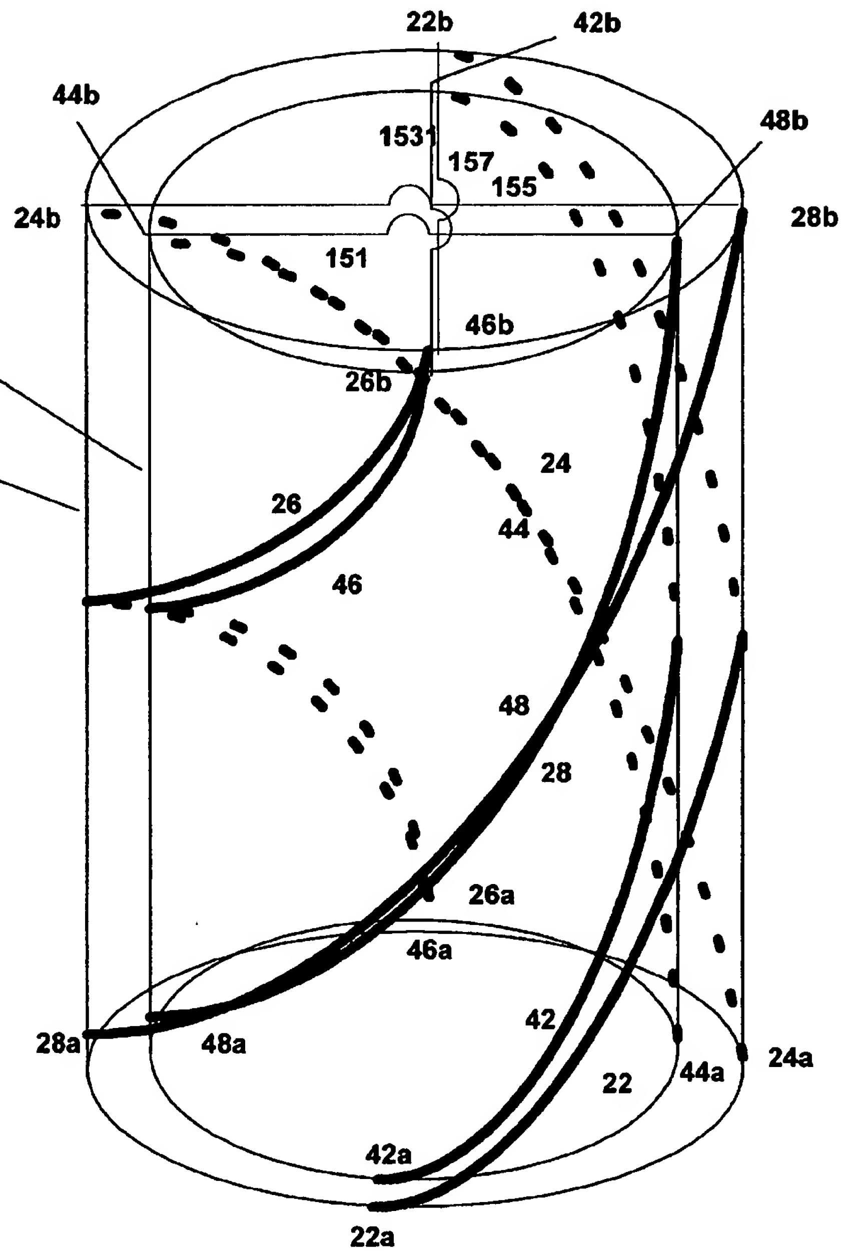
42a
44a
46a
48a
112
114
116
118
122
124
126
128
110
110
110
110
120
120
120
120
120
86
88
96
98
Transmit 90 Degree Hybrid Coupler
81
Receive 90 Degree Hybrid Coupler
91
82
84
94
92
110
120
83
89
99
93
18
12
14

Figure 3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44
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48
28
26a
46a
42
28a
48a
44a
24a
22
42a
22a

Figure 4

DUAL FREQUENCY BAND QUADRIFILAR HELIX ANTENNA SYSTEMS AND METHODS

FIELD OF THE INVENTION

The present invention relates generally to antenna systems for user terminal handsets. More particularly, the present invention relates to quadrifilar helix antenna systems for use with mobile telephone user handsets.

BACKGROUND OF THE INVENTION

Cellular and satellite communication systems are well known in the art for providing a communications link between mobile telephone users and stationary users or other mobile users. These communications links may carry a variety of different types of information, including voice, data, video and facsimile transmissions. In typical cellular systems, wireless transmissions from mobile users are received by local, terrestrial based, transmitter/receiver stations. These local base stations or "cells" then retransmit the mobile user signals, via either the local telephone system or the cellular system, for reception by the intended receive terminals.

Many cellular systems rely primarily or exclusively on line-of-sight communications. In these systems, each local transmitter/receiver has a limited range, and consequently, a large number of local cells may be required to provide communications coverage for a large geographic area. The cost associated with providing such a large number of cells may prohibit the use of cellular systems in sparsely populated regions and/or areas where there is limited demand for cellular service. Moreover, even in areas where cellular service is not precluded by economic considerations, "blackout" areas often arise in terrestrial based cellular systems due to local terrain and weather conditions.

As such, it has been proposed to provide a combined, half-duplex, cellular/satellite communications network that integrates a limited terrestrial based cellular network with a satellite communications network to provide communications for mobile users over a large geographical area where it may be impractical to provide cellular service. In the proposed system, terrestrial based cellular stations would be provided in high traffic areas, while an L-Band satellite communications network would provide service to remaining areas. In order to provide both cellular and satellite communications, the user terminal handsets used with this system would include both a satellite and a cellular transceiver. Such a combined system could provide full communications coverage over a wide geographic area without requiring an excessive number of terrestrial cells.

In this proposed system, which is known as the Asian Cellular Satellite System, the satellite network would be implemented as one or more geosynchronous satellites orbiting approximately 22,600 miles above the equator. These satellites could provide spot beam coverage over much of the far east, including China, Japan, Indonesia and the Philippines. In this system, signals transmitted to the satellite will fall within the 1626.5 MHz to 1660.5 MHz transmit frequency band, and the signals transmitted from the satellite will fall within the 1525 MHz to 1559 MHz receive frequency band.

While integrating satellite and cellular service together in a dual-mode system may overcome many of the disadvantages associated with exclusively terrestrial based cellular systems, providing dual-mode user terminal handsets that meet consumer expectations regarding size, weight, cost, ease of use and communications clarity is a significant challenge. Consumer expectations relating to such physical characteristics and communications performance of handheld mobile phones have been defined by the phones used with conventional cellular systems, which only include a single transceiver that communicates with a cellular node which typically is located less than 20 miles from the mobile user terminal. By way of contrast, the handheld user terminals which will be used with the Asian Cellular Satellite System must include both a cellular and a satellite transceiver. Moreover, the large free space loss associated with the satellite communications aspect of the system may significantly increase the power and antenna gain which must be provided by the antenna for the satellite transceiver on the user terminal handset, as the signals transmitted to or from the satellites undergo a high degree of attenuation in traveling the 25,000 or more miles that typically separates the user handset from the geosynchronous satellites.

Furthermore, the satellite aspects of the network also may impose additional constraints on the user terminal handsets. For instance, the satellite transceiver provided with the user terminal handset preferably should provide a quasi-hemispherical antenna radiation pattern, in order to avoid the need to track a desired satellite. Additionally, the antenna which provides this quasi-hemispherical radiation pattern should transmit and receive a circularly polarized waveform, so as both to minimize the signal loss resulting from the arbitrary orientation of the satellite antenna on the user terminal with respect to the satellite and to avoid the effects of Faraday rotation which may result when the signal passes through the ionosphere. Moreover, the satellite antenna on the handheld transceiver should also have a low front-to-back ratio and low gain at small elevation angles in order to provide a low radiation pattern noise temperature. Additionally, as discussed above, the satellite network transmits signals in one frequency band (the transmit frequency subband) and receives signals in a separate frequency band (the receive frequency subband) in order to minimize interference between the transmit and receive signals. Thus the antenna on the handheld satellite transceiver preferably provides an acceptable radiation pattern across both the transmit and receive frequency subbands.

In light of the above constraints, there is a need for handheld satellite transceivers, and more specifically, antenna systems for such transceivers, capable of transmitting and receiving circularly polarized waveforms which provide a relatively high gain quasi-hemispherical radiation pattern over separate transmit and receive frequency subbands so as to be capable of receiving signals from, or transmitting signals to, satellites which may be located anywhere in the hemisphere. Moreover, given the handheld nature of the user terminals and consumer expectations of an antenna which is conveniently small for ease of portability, the satellite antenna system capable of meeting the aforementioned requirements should fit within an extremely small physical volume. These user imposed size constraints may also place limitations on the physical volume required by the antenna feed structure and any matching, switching or other networks required for proper antenna operation. Thus, for instance, in the Asian Cellular Satellite System, the satellite network link budgets require the satellite antenna system on the handheld phone to be capable of providing a net gain of at least 2 dBi over all elevation angles exceeding 45°, where the net gain is defined as the actual gain or "directivity" provided by the antenna minus any matching, absorption or other losses incurred in the antenna feed structure. Additionally, the antenna must also have an axial ratio of less than 3 dB while providing good front to back ratio over

the entire receive frequency subband. These performance characteristics must be provided by an antenna which, along with any associated impedance matching circuits or other components, fits within a cylinder 13 centimeters in length and 13 millimeters in diameter.

Helix antennas, and in particular, multifilar helix antennas, are relatively small antennas that are well suited for various applications requiring circularly polarized waveforms and a quasi-hemispherical beam pattern. A helix antenna is a conducting wire wound in the form of a screw thread to form a helix. Such helix antennas are typically fed by a coaxial cable transmission line which is connected at the base of the helix. A multifilar helix antennas is a helix antenna which includes more than one radiating element. Each element of such a multifilar helix antenna is generally fed with an equal amplitude signal that is separated in phase by 360°/N, where N is the number of radiating antenna elements. As the phase separation between adjacent elements varies from 360°/N, the antenna pattern provided by the multifilar helix antenna tends to degrade significantly. Accordingly, the feed structure which couples the signals between the elements of a multifilar helix antenna and the transmitter/receiver preferably introduces minimal or no phase distortions so that such degradation of the antenna pattern is minimized or prevented.

A common type of multifilar helix antenna is the quadrifilar helix. The quadrifilar helix antenna is a circularly polarized antenna which includes four orthogonal radiating elements arranged in a helical pattern (which may be fractional turn), which are excited in phase quadrature (i.e., the radiated energy induced into or from the individual radiating elements is offset by 90° between adjacent radiating elements).

Quadrifilar helix antennas can be operated in several modes, including axial mode, normal mode or a proportional combination of both modes. To achieve axial mode operation, the axial length of each antenna element is typically several times larger than the wavelength corresponding to the center frequency of the frequency band over which the antenna is to operate. Operated in this mode, a quadrifilar helix antenna can provide a relatively high gain radiation pattern. However, such a radiation pattern is highly directional (i.e., it is not quasi-hemispherical) and hence axial mode operation is typically not appropriate for satellite communications terminals that do not include means for tracking the satellite.

Operated in the normal mode, each helix of a quadrifilar helix antenna is typically balun fed at the top, and the helical arms are typically of resonant length (i.e., ¼λ, ½λ, ¾λ or λ in length, where λ is the wavelength corresponding to the center frequency of the frequency band over which the antenna is to operate). These elements are wound on a small diameter with a large pitch angle. In this mode, the antenna typically provides the quasi-hemispherical radiation pattern necessary for mobile satellite communications, but unfortunately, the antenna only provides this gain over a relatively narrow bandwidth situated about the resonant frequency. Moreover, the natural bandwidth of the antenna is proportional to the diameter of the cylinder defined by the quadrifilar helix antenna, and thus, all else being equal, the smaller the antenna the smaller the operating bandwidth. As discussed above, certain emerging cellular and satellite phone applications have relatively large transmit and receive operating bandwidths. These bandwidths may approach or even exceed the bandwidth provided by quadrifilar helix antennas operated in normal mode, and this is particularly true where other system requirements significantly restrict the maximum diameter of the antenna.

Quadrifilar antennas have previously been used in a number of mobile L-Band satellite communication applications, including INMARSAT, NAVSTAR, and GPS. However, nearly all these prior art antennas were physically much too large to satisfy the size requirements of emerging satellite phone applications. Moreover, these prior art antennas also generally do not meet the size constraints imposed by these emerging applications while also providing the gain, axial ratio, noise temperature, front-to-back ratio and broadband performance that are required by these emerging applications. Accordingly, a need exists for a new, significantly smaller, satellite phone antenna system that is capable of providing a quasi-hemispherical antenna pattern with positive gain over separate transmit and receive frequency subbands.

SUMMARY OF THE INVENTION

In view of the above limitations associated with existing antenna systems, it is an object of the present invention to provide physically small quadrifilar helix antenna systems for satellite and cellular phone networks.

Another object of the present invention is to provide a quadrifilar helix antenna system capable of providing a radiation pattern with a positive gain, quasi-hemispherical radiation pattern at separate transmit and receive frequency subbands.

It is still a further object of the present invention to provide a quadrifilar helix antenna system for satellite and cellular phones that has a simplified feed structure and that minimizes the phase distortions introduced in the feed network.

These and other objects of the present invention are provided by antenna systems which use switched concentric transmit and receive quadrifilar helix antennas to provide half-duplex communications over separate transmit and receive frequency bands. These antenna systems capitalize on the size, gain, polarization, and radiation pattern characteristics achievable with quadrifilar helix antennas, while avoiding the bandwidth limitations of such antennas, through the use concentrically arranged, yet decoupled, transmit and receive antennas.

In a preferred embodiment of the present invention, concentrically arranged transmit and receive quadrifilar helix antennas are provided, each of which comprise two bifilar helices arranged orthogonally and excited in phase quadrature. These antennas are each associated with coupling means, which electrically connect the transmit and receive antennas to the transmitter and receiver, respectively. Also provided are a pair of disconnecting means, the first of which electrically isolates the transmit quadrifilar helix antenna from the receiver when the user terminal is in receive mode, and the second of which similarly isolates the receive quadrifilar helix antenna from the transmitter during periods of transmission. These antenna disconnecting means may comprise a plurality of switching means interposed along each electrical connection between each quadrifilar helix antenna and the transmitter/receiver. Such switches could comprise PIN diodes, gallium arsenide field effect transistors, or other electrical, electrical mechanical, or mechanical switching mechanisms known to those of skill in the art.

In another embodiment of the present invention, the antenna coupling means comprise 90° hybrid couplers. In this embodiment, the transmit and receive quadrifilar helix antennas each may comprise a first filar coupled at its origin to one of the output ports on the antennas respective 90°

hybrid coupler, a second filar coupled at its origin to the other output port of the 90° hybrid coupler, and third and fourth filars which are coupled at their origin to a reference voltage, and wherein the first and third filars and the second and fourth filars are electrically connected at their distal ends. In this embodiment, the quadrature input to these 90° hybrid couplers is also typically connected to the reference voltage through a 50 ohm resistor.

In yet another embodiment of the present invention, the transmit quadrifilar helix antenna is substantially disposed within the cylinder which is defined by the radiating elements of the receive quadrifilar helix antenna. In this embodiment, the bifilar helices forming the transmit quadrifilar helix antenna may be radially aligned with the bifilar helices forming the receive quadrifilar helix antenna. In another aspect of the present invention, both the transmit and receive quadrifilar helix antennas are configured to transmit/receive right hand circularly polarized signals. Furthermore, each of these filar helices may comprise a helix with a pitch angle from about 55 to 85 degrees.

Thus, the antenna systems of the present invention comprise switched, concentrically arranged transmit and receive quadrifilar helix antennas which provide half-duplex communications over separate transmit and receive frequency bands. These antenna systems provide the gain, bandwidth, polarization, and radiation pattern characteristics necessary for emerging mobile satellite communications applications, in a physical package which is conveniently small and meets consumer expectations relating to ease of portability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a quadrifilar helix antenna system capable of operating over two frequency bands according to the present invention;

FIG. 2 is a perspective view of a pair of concentric transmit and receive quadrifilar helix antennas according to the present invention;

FIG. 3 is a schematic diagram illustrating specific embodiments of the antennas, coupling networks and disconnecting mechanisms of the present invention; and

FIG. 4 is a perspective view of a pair of concentric transmit and receive quadrifilar helix antennas according to the present invention with the receive quadrifilar helix antenna disposed within the cylinder defined by the transmit quadrifilar helix antenna.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Additionally, while the antenna systems of the present invention are particularly advantageous for use in certain satellite communications applications, it will be understood by those of skill in the art that these antenna systems may be advantageously used in a variety of applications, including cellular, terrestrial based communications systems, and thus the present invention should not be construed as limited in any way to antenna systems for use with satellite communication terminal handsets. Like numbers refer to like elements throughout.

An embodiment of a handheld wireless communications terminal **10** according to the present invention is illustrated in FIG. **1**. Terminal **10** generally comprises an antenna system **18**, a transmitter **12**, a receiver **14** and a user interface **16**. As illustrated in FIG. **1**, the antenna system **18** of the handheld terminal **10** employs dual quadrifilar helix antennas **20**, **40** to provide for dual band, half-duplex wireless communications. In a preferred embodiment, antenna system **100** incorporates concentric, substantially overlapping quadrifilar helix antennas **20**, **40** which are each fed by a single 90° hybrid coupler **81**, **91** (not shown in FIG. **1**) to provide a physically small, cost effective antenna system capable of meeting the stringent gain, bandwidth, radiation pattern and other requirements of emerging cellular/satellite phone applications.

As depicted in FIG. **1**, the dual frequency band quadrifilar helix antenna system **100** according to the present invention employs two separate quadrifilar helix antennas, transmit antenna **20** and receive antenna **40**. Each antenna **20**, **40** is coupled to an antenna feed network **80**, **90**. The transmit feed network **80** feeds a source signal from transmitter **12** to the individual elements of the transmit quadrifilar helix antenna **20**, whereas the receive feed network **90** combines the signal received by the individual elements of receive quadrifilar helix antenna **40** and feeds this combined signal to receiver **14**. Additionally, antenna disconnecting means **70** are provided between receive feed network **90** and receive antenna **40**. These disconnecting means **70** are used to electrically isolate the receive antenna **40** from the transmit network **20**, **60**, **80**, **12** during periods of transmission. Similarly, switching means **60** are also provided between transmit feed network **80** and transmit antenna **20**, which electrically isolate the transmit antenna **20** when the handset **10** is operating in receive mode.

The antenna system depicted in FIG. **1** operates as follows. When the user handset **10** is in the receive mode, bias signal **62** is activated which excites the disconnect means **60** in the transmit antenna **20** feed path, thereby open circuiting the elements of the transmit antenna **20** in order to electrically isolate transmit antenna **20** from receive antenna **40**. Similarly, when user handset **10** operates in the transmit mode, bias signal **72** is activated, which excites disconnect means **70** in the receive antenna **40** path in order to electrically isolate receive antenna **40** from transmit antenna **20**. As will be understood by those of skill in the art, transmit and receive disconnect means **60**, **70** need not actually provide a true open circuit in order to effectively electrically isolate the antenna which is not in use; they simply need to provide sufficient impedance such that only a minimal amount of energy is coupled into the "OFF" antenna. Various means of providing such an open circuit are known to those of skill in the art, such as reverse biased PIN diodes, Gallium arsenide field effect transistors, and various other electrical, electromechanical and mechanical switching mechanisms.

As illustrated in FIG. **2**, transmit and receive quadrifilar helix antennas **20**, **40** are each comprised of four radiating helical antenna elements **22**, **24**, **26**, **28**; **42**, **44**, **46**, **48** or "filars". A filar is typically implemented as a wire or strip, such as **22**, wrapped in a helical shape along the length of a coaxial supporting tube, thereby defining a cylinder of a constant diameter and a height equal to the axial length of the antenna elements which comprise each antenna. Thus each antenna **20**, **40** comprises a pair of bifilar helices. In a preferred embodiment, the elements **22**, **24**, **26**, **28**; **42**, **44**, **46**, **48** of each quadrifilar helix antenna **20**, **40** are excited in phase quadrature and are physically spaced from each other by 90°. Note that as used herein, it is intended that the word

"helix" not imply a plurality of turns. In particular, a "helix" as used herein may constitute less than one full turn.

Alternative embodiments within the scope of the present invention include transmit and/or receive quadrifilar helix antennas **20, 40** having radiating elements **22, 24, 26, 28; 42, 44, 46, 48** which are helical in the sense that they each form a coil or part coil around an axis, but also change in diameter from one end to the other. Thus, while the preferred embodiment of the transmit and receive antennas **20, 40** have helical elements defining a cylindrical envelope, it is possible to implement one or both of these antennas to have elements defining instead a conical envelope or another surface of revolution.

The twist of the individual helices **22, 24, 26, 28; 42, 44, 46, 48** may be right hand or left hand, where each element **22, 24, 26, 28; 42, 44, 46, 48** comprising a particular antenna **20, 40** has the same direction of twist. Where antennas **20, 40** are origin fed in endfire mode, by IEEE and industry conventions, a left hand twist is generally used to receive and transmit right hand circularly polarized waveforms, whereas a right hand twist generally is used to receive and transmit left hand circularly polarized waveforms. In a preferred embodiment of the present invention, both the transmit and receive quadrifilar helix antennas **20, 40** are configured to transmit and receive like polarized waveforms.

The radiation pattern provided by each of the quadrifilar helix antennas **20, 40** depicted in FIG. **2** is primarily a function of the helix diameter, pitch angle (which is a function of the number of turns per unit axial length of the helix) and the actual length of the elements which comprise the antenna. In a preferred embodiment of the present invention, the helical antenna elements of both the transmit and receive antennas **20, 40** are each approximately $\lambda/2$ in electrical length, where λ is the wavelength corresponding to the center frequency of the transmit (for transmit antenna **20**) or receive (for receive antenna **40**) frequency band. In this embodiment, antennas 20, 40 preferably have pitch angles from about 55 to 85 degrees. In this preferred range, the lower pitch angles provide more hemispherical coverage, while the higher pitch angle values concentrate the radiation pattern (and hence provides greater directivity) over a smaller solid angle than hemispherical coverage for element lengths on the order of ½ wavelength. Given the specific requirements of the system in which the antennas are to be used, a judicious choice of pitch angle may be made to provide the optimum tradeoff between coverage and directivity. These quadrifilar helix antennas **20, 40** operate in standing wave mode, providing a quasi-hemispherical radiation pattern (or perhaps a slightly more directional pattern) for a relatively narrow bandwidth about the resonant frequency. However, by providing separate transmit and receive quadrifilar helix antennas **20, 40**, it is possible to use the quadrifilar helix antenna systems of the present invention in mobile satellite communications applications with widely separated transmit and receive frequency subbands.

The four individual antenna elements **22, 24, 26, 28; 42, 44, 46, 48** that comprise transmit and receive quadrifilar helix antennas **20, 40** each have an origin which is the end proximate the feed networks, and a distal end. As indicated best in FIG. **3**, the distal ends ***22b*, *26b*** of transmit quadrifilar helix antenna elements **22** and **26** are electrically connected via wire or strip **151** to form a bifilar loop, with the origin ***22a*** of element **22** connected to the transmit feed network **80** (which in FIG. **3** is implemented as 90° hybrid coupler **81**) and the origin ***26a*** of element **26** coupled to ground. Similarly, the distal ends ***24b*, *28b*** of elements **24** and **28** are electrically connected via wire or strip **153** to form a second

bifilar loop, with the origin ***24a*** of element **24** connected to the second output of the transmit feed network and the origin ***28a*** of element **28** coupled to ground. This embodiment of quadrifilar helix antenna **20** is referred to as a closed loop embodiment, as the elements of the antenna are electrically connected at their distal ends. These are to be distinguished from open-loop quadrifilar helix antennas, which comprise four helical elements each of which is open-circuited at its distal end.

In a preferred embodiment of transmit antenna **20**, bifilar loops **22, 26; 24, 28** are symmetrical. Accordingly, electrical connections **151, 153** are preferably implemented as identically shaped conductive wires or strips arranged so as to provide the short-circuits which form bifilar loops **22, 26; 24, 28** while electrically isolating bifilar loop **22, 26** from bifilar loop **24, 28**. Such a symmetrical arrangement of electrical connections **151, 153** minimizes the variation in phase between adjacent elements from the ideal phase offset of 90°.

Similarly, on receive quadrifilar helix antenna **40**, the distal ends ***42b*, *46b*** of elements **42** and **46** are electrically connected via wire or strip **155** to form a first bifilar loop, and the distal ends ***44b*, *48b*** or elements **44** and **48** are electrically connected via wire or strip **157** to form a second bifilar loop. The origin ***42a*, *44a*** of elements **42** and **44** are coupled to receive feed network **90** (which in FIG. **3** is implemented as 90° hybrid coupler **91**), and the orgins ***46a*, *48a*** of elements **46** and **48** are connected to ground. Both the transmit and receive antennas **20, 40** may additionally include a radome. In the preferred embodiment, this radome is a plastic tube with an end cap.

The closed loop embodiment of the quadrifilar helix antenna of the present invention solves a problem that may arise when open loop quadrifilar helix antennas are used in mobile phone applications. Specifically, in applications which require a small antenna diameter, a bottom-fed ½ wavelength open loop antenna has a nearly open circuit impedance (1000 ohms or more) at the resonant frequency. Such an impedance may be too large to transform to the desired impedance, which is often on the order of 50 ohms as the antennas are typically connected to transmitter **12** and receiver **14** via one or more 50 ohm impedance coaxial cables, and thus maximum power transfer may not be obtainable as the impedance of the antennas cannot be matched to the impedance of the source transmission line. The resonant resistance of the closed loop bottom-fed $\lambda/2$ length element quadrifilar helix antenna, on the other hand, is in the region of 4–12 ohms. This may be transformed to the order of 50 ohms to match the impedance of the transmission source by known impedance transformation techniques, such as a radio frequency transformer. However, for certain element lengths other than ½ wavelength, such as ¾ wavelength elements, the open circuit impedance may be much lower so as to be transformable to the order of 50 ohms.

As shown in FIG. **2**, in the preferred embodiment of the present invention, the transmit and receive quadrifilar helix antennas **20, 40** are concentrically arranged in an overlapping relationship. This can minimize the physical volume of the antenna system **18**. Typically, the receive frequency band encompasses lower frequencies than the transmit frequency band. As such, in the preferred embodiment, the antenna elements **22, 24, 26, 28** forming the transmit quadrifilar helix antenna **20** are shorter than the elements **42, 44, 46, 48** on the receive quadrifilar helix antenna **40** and a similar antenna radiation pattern can be achieved with a smaller antenna diameter. Thus, in this case, the transmit antenna **20** is

typically disposed within the cylinder defined by the receive quadrifilar helix antenna 40. However, as illustrated in FIG. 4, antenna system 10 may also be designed so that receive quadrifilar helix antenna 40 is disposed within the cylinder defined by the transmit quadrifilar helix antenna 20. As shown in FIG. 2, in the preferred embodiment, the elements 22, 24, 26, 28; 42, 44, 46, 48 of transmit and receive quadrifilar helix antennas 20, 40 are radially aligned. Such radial alignment serves to minimize couplings between the "ON" and "OFF" antennas.

The elements 22, 24, 26, 28; 42, 44, 46, 48 of transmit and receive quadrifilar helix antennas 20, 40 are preferably comprised of a continuous strip of electrically conductive material such as copper. These radiating elements 22, 24, 26, 28; 42, 44, 46, 48 may be printed on a flexible, planar dielectric substrate such as fiberglass, TEFLON, polyimide or the like via etching, deposition or other conventional methods. This flexible dielectric base may then be rolled into a cylindrical shape, thereby converting the linear strips into helical antenna elements 22, 24, 26, 28; 42, 44, 46, 48. However, while the technique of forming a quadrifilar helix antenna described above is the preferred method, it will be readily apparent to those of skill in the art that transmit and receive quadrifilar helix antennas 20, 40 may be implemented in a variety of different ways, and that a cylindrical support structure is not even required.

As indicated in FIG. 1, transmit and receive feed networks 80, 90 are provided to phase split the energy for radiation in the transmit mode and for combining the received radiated energy in receive mode. These feed networks 80, 90 can be implemented as any of a variety of known networks for feeding a quadrifilar helix antenna, such as the combination of a hybrid coupler and two symmetrizer modules disclosed in U.S. Pat. No. 5,255,005 to Terret et al.

Quadrifilar helical antennas such as antennas 20, 40 are known to be capable of radiating right or left hand circularly polarized signals when fed from the top in a backfire mode, fed in the middle via a selectable up or down mode, or when bottom fed in a forward fire reverse twist mode. However, top fed versions tend to require sleeve baluns in the center of the cylindrical structure, which may be difficult to fabricate. This is particularly true at the frequencies required by microwave satellite phone user terminals, due to the small diameter of the helical antenna structure required by such phones. Similarly, center fed quadrifilar helical antennas may also be difficult to fabricate. In a preferred embodiment, this invention solves these fabrication problems by using origin-fed networks which drives the two closed bifilar wavelength loops on each quadrifilar helix antenna 20, 40.

Such a preferred embodiment of the feed networks 80, 90 is depicted in FIG. 3. As shown in FIG. 3, each of the feed networks 80, 90 is implemented as a 90° hybrid coupler 81, 91 which is coupled to the bifilar loops which form the transmit and receive antennas 20, 40. As illustrated in FIG. 3, the transmit feed network 80 comprises a single 90° hybrid coupler 81, with inputs 82, 84 and outputs 86, 88. Input 82 is coupled to the transmission signal source 12 and input 84 is coupled to ground through a resistive termination 89.

Typically, the transmission signal source 12 is coupled to the transmit 90° hybrid coupler 81 through a coaxial cable 83. Coaxial cable typically has an impedance of approximately 50 ohms. In order to maximize the energy transfer from the transmission signal source 12 to the transmit quadrifilar helix antenna 20, it is preferable to match the impedance of the transmission source 12 and the impedance of the transmit antenna 20. Such matching can be accomplished by using known techniques to raise the impedance of antenna elements 22, 24 to approximately 50 ohms, and implementing resistor 89 as a 50 ohm resistor. As the λ/2 length antenna elements 22, 24, 26, 28 implemented in a preferred embodiment of the present invention have a resistance of approximately 4–12 ohms at resonance, an impedance transformation of approximately a factor of four is necessary to match the impedance of the transmit quadrifilar helix antenna 20 to the impedance at the input of the transmit 90° hybrid coupler 81. Those of skill in the art will recognize that there are a variety of techniques which can be used to accomplish this impedance transformation, such as the use of a radio frequency balun with a four-to-one impedance transformation or a variety of small surface mount radio frequency transformers.

As illustrated best in FIG. 3, transmit 90° hybrid coupler 81 divides the input source signal into two, equal amplitude output signals, which are offset from each other by 90° in phase. Output 86 is coupled to the first of the two λ long bifilar loops 22, 26 which comprise the transmit quadrifilar helix antenna 20, and output 88 feeds the second λ long bifilar loop 24, 28.

As also is illustrated in FIG. 3, the receive feed network 91 is preferably implemented in the exact same manner as the transmit feed network 81, except that the receive feed network 91 is used to combine and deliver induced power to the receiver 14 as opposed to delivering a signal to the antenna for radiation. Accordingly, a receive 90° hybrid coupler 91 having input ports 96, 98 and output ports 92, 94 is used to combine the energy received by receive quadrifilar helix antenna 40 and deliver this induced power to receiver 14. Input port 96 of the receive 90° hybrid coupler 91 is coupled to the first bifilar loop 42, 46 of receive quadrifilar helix antenna 40, and port 98 is coupled to the second bifilar loop 44, 48. Output 92 of the receive 90° hybrid coupler is coupled to the receiver 14 through a coaxial cable 93, and output port 94 is coupled to ground through resistor 99.

As will be readily understood by those of skill in the art, 90° hybrid couplers 81 and 91 can be implemented in a variety of different ways, such as distributed quarter wave transmission lines or as lumped element devices. In the preferred embodiment, lumped element 90° hybrid splitter/combiners are used as they are typically smaller than corresponding distributed branch line couplers and also maintain a phase difference of almost exactly 90° between their two output ports.

FIG. 3 also illustrates a preferred method of electrically coupling transmit and receive quadrifilar helix antennas 20, 40 to their respective feed networks 80, 90. As discussed above, in the preferred embodiment both the transmit and receive antennas 20, 40 are implemented as a pair of wavelength (λ) long, electrically connected, bifilar loops. As shown in FIG. 3, transmit and receive antennas 20, 40 are fed by connecting λ long loops 22, 26; 42, 46 to the 0° input/output of their respective 90° hybrid couplers 81, 91 and coupling the other bifilar loop 24, 28; 44, 48 to the other input/output of the respective 90° hybrid coupler. The origins of elements 26, 28 of the transmit and quadrifilar helix antenna 20, 40, as well as the origins of elements 46, 48 of the receive quadrifilar helix antenna are coupled to electrical ground. In this manner, during transmission each element of the transmit and receive quadrifilar helix antennas 20, 40 are excited in phase quadrature by equal amplitude signals.

As shown in FIG. 2, in the preferred embodiment, transmit and receive quadrifilar helix antennas 20, 40 are imple-

mented in a concentric, substantially overlapping arrangement. While this arrangement minimizes the physical dimensions of the antenna system, the close proximity of the transmit antenna elements **22, 24, 26, 28** and the receive antenna elements **42, 44, 46, 48** provides the possibility that received energy may be coupled in the transmit antenna **20** or that energy induced into transmit antenna **20** may be coupled into receive antenna **40**. Such coupling may be undesirable because it reduces the power that is transferred to transmit antenna **20** for transmission or that is received from receive antenna **40**. Moreover, the coupling also can adversely impact the radiation patterns of the antennas.

According to the present invention, it has been discovered that transmit and receive quadrifilar helix antennas **20, 40** can be effectively electrically isolated by open-circuiting the elements of the "OFF" antenna. When such an open-circuit is provided, the "ON" antenna essentially operates as if the "OFF" antenna was not present. In the preferred embodiment of the present invention, the "OFF" antenna is open circuited via switching means **112, 114, 116, 118; 122, 124, 126, 128** which are coupled to each of the elements of transmit and receive quadrifilar helix antennas **20, 40** at the element origins. These switches are activated by a bias signal to provide an open circuit at the origin of each element **22, 24, 26, 28** of transmit antenna **20** when user terminal **10** is in the receive mode, and to provide an open circuit at the origin of each element **42, 44, 46, 48** of receive antenna **40** when the user terminal **10** is in the transmit mode.

As will be understood by those of skill in the art, switching means **112, 114, 116, 118; 122, 124, 126, 128** can be provided by various electrical, electro-mechanical, or mechanical switches. However, electrical switches are preferred, due to their reliability, low cost, small physical volume and ability to switch on and off at the high speeds required by emerging digital communications modes of operation. These electrical switches can readily be implemented as small surface mount devices on a microelectronic substrate such as a stripline or microstrip printed circuit board. Preferably, a single microelectronic substrate contains both these switches and the components comprising the transmit and receive feed networks. In one embodiment of the present invention, switching means **112, 114, 116, 118; 122, 124, 126, 128** are implemented as PIN diodes.

A PIN diode is a semiconductor device that operates as a variable resistor over a broad frequency range from the high frequency band through the microwave frequency bands. These diodes have a very low resistance, of less than 1 ohm, when in a forward bias condition. Alternatively, these diodes may be zero or reverse biased, where they behave as a small capacitance of approximately one picofarad shunted by a large resistance of as much as 10,000 ohms. Thus, in forward bias mode, the PIN diode acts as a short-circuit, while in reverse bias mode, the PIN diode effectively acts as an open-circuit. In this embodiment, the PIN diodes are implemented as discrete components coupled to the origin of each element of the transmit and receive quadrifilar helix antennas **20, 40**.

In the PIN diode embodiment, when the communications handset **10** is in receive mode, a D.C. bias current is applied to each PIN diode in the transmit circuit branch where it reverse biases these diodes thereby creating an open circuit at the origin of each element **22, 24, 26, 28** of quadrifilar helix antenna **20**. At the same time, a forward bias current is applied to the PIN diodes in the receive circuit branch creating a lower resistance connection to the receive circuit branch. Consequently, the receive circuit branch PIN diodes operate in forward bias mode, thereby coupling the elements **42, 44, 46, 48** of receive quadrifilar helix antenna **40** to receiver **14**. As will readily be understood by those of skill in the art, when communications terminal **10** is operating in transmit mode, a zero or reverse bias signal is applied to the PIN diodes in the receive circuit branch and a forward bias is applied to the PIN diodes in the transmit circuit branch, thereby coupling antenna **20** to transmitter **12** and creating an open-circuit at the origin of quadrifilar helix antenna **40**.

In an alternative embodiment shown in FIG. **3**, Gallium arsenide field effect transistors (GaAs FETs) are used instead of PIN diodes to implement switches **112, 114, 116, 118; 122, 124, 126, 128**. These devices may be preferred over PIN diodes because they operate in reverse bias mode when a bias signal is absent, thereby avoiding the power drain inherent with PIN diodes which require a bias current for forward bias operation. Moreover, as shown in FIG. **3**, each GaAs FET uses an inductor to anti-resonate and therefore isolate the switch in the "OFF" mode. This operation significantly increases the electrical isolation of the "OFF" circuits. In the "ON" mode, the inductor is rendered desirably ineffective as it is effectively shorted by the "ON" resistance of the associated GaAs FET. Furthermore, the drains and sources of the GaAs FET switches are operated at direct current ground potential and resistance. This attribute renders these GaAs FET free from ordinary electrostatic discharge concerns typically associated with use of GaAs FET near antenna circuitry. In this embodiment, the GaAs FET switches **112, 114, 116, 118; 122, 124, 126, 128** are implemented as surface mount components on the stripline printed circuit board containing transmit and receive 90° hybrid couplers **81, 83**.

In a preferred embodiment, the 90° hybrid coupler **81**, 50 ohm resistor **89**, and GaAs FET switches **112, 114, 116, 118** of the transmit branch are implemented as surface mount components on a stripline or microstrip printed circuit board. Preferably, a multilayer board is used which includes a ground circuit between its top and bottom layers. At one end of the printed circuit board, four contacts may be provided to couple the feed network to the elements of the transmit quadrifilar helix antenna **20**. On the other end of the printed circuit board, provision may be made for attaching the coaxial transmission line from transmitter **12**. In this case, the identical surface mount components of the receive branch are preferably mounted on the opposite side of the printed circuit board.

In the drawings, specification and examples, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, these terms are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims. Accordingly, those of skill in the art will themselves be able to conceive of embodiments of the antenna system other than those explicitly described herein without going beyond the scope of the present invention.

That which is claimed is:

1. A half-duplex antenna system for providing electrical signals to a receiver and for transmitting electrical signals from a transmitter, comprising:

a receive quadrifilar helix antenna comprising two bifilar helices arranged orthogonally and excited in phase quadrature;

a transmit quadrifilar helix antenna comprising two bifilar helices arranged orthogonally and excited in phase quadrature, positioned concentrically with said receive quadrifilar helix antenna;

first coupling means for coupling the signal from said receive quadrifilar helix antenna to said receiver;

first disconnecting means for electrically isolating the bifilar helices of said transmit quadrifilar helix antenna from said receiver during periods of transmission;

second coupling means for coupling the signal from said transmitter to said transmit quadrifilar helix antenna; and

second disconnecting means for electrically isolating the bifilar helices of said receive quadrifilar helix antenna from said transmitter when the antenna system is operating in the receive mode; and

wherein one of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna is disposed within the cylinder defined by the other of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna.

2. The antenna system of claim **1**, wherein said first disconnecting means comprises a plurality of switching means interposed along each electrical connection between said transmitter and said transmit quadrifilar helix antenna, and wherein said second disconnecting means comprises a plurality of switching means interposed along each electrical connection between said receiver and said receive quadrifilar helix antenna.

3. The antenna system of claim **2**, wherein said switching means comprise PIN diodes.

4. The antenna system of claim **2**, wherein said switching means comprise gallium arsenide field effect transistors.

5. The antenna system of claim **1**, wherein said first coupling means comprises a first 90° hybrid coupler having first and second input ports and first and second output ports and said second coupling means comprises a second 90° hybrid coupler having first and second input ports and first and second output ports.

6. The antenna system of claim **5**,

wherein said transmit quadrifilar helix antenna comprises a first filar coupled at its origin to the first output port on said first 90° hybrid coupler, a second filar coupled at its origin to the second output port of said first 90° hybrid coupler, and third and fourth filars coupled at their origin to a first reference voltage, and wherein said first and third filars are electrically connected at their distal ends and said second and fourth filars are electrically connected at their distal ends; and

wherein said receive quadrifilar helix antenna comprises a first filar coupled at its origin to the first output port on said second 90° hybrid coupler, a second filar coupled at its origin to the second output port of said second 90° hybrid coupler, and third and fourth filars coupled at their origin to said first reference voltage, and wherein said first and third filars are electrically connected at their distal ends and said second and fourth filars are electrically connected at their distal ends.

7. The antenna system of claim **5**, wherein said first and second 90° hybrid couplers comprise lumped element 90° hybrid couplers.

8. The antenna system of claim **1**, wherein said transmit antenna is configured to transmit a right hand circularly polarized signal and wherein said receive antenna is configured to receive a right hand circularly polarized signal.

9. The antenna system of claim **1**, wherein each of said filar helices comprises a helix with a pitch angle greater than about 55 degrees and less than about 85 degrees.

10. The antenna system of claim **1**, further comprising at least one microelectronic substrate, and wherein said transmit quadrifilar helix antenna, said receive quadrifilar helix antenna and said first and second coupling/disconnect means are implemented on said at least one microelectronic substrates.

11. The antenna system of claim **1**, wherein the bifilar helices forming said transmit quadrifilar helix antenna are radially aligned with the bifilar helices forming said receive quadrifilar helix antenna.

12. A half-duplex antenna system for providing electrical signals to a receiver and for transmitting electric signals from a transmitter, comprising:

a transmit 90° hybrid coupler having two output ports fed by said transmitter;

a receive 90° hybrid coupler having two input ports feeding said receiver;

concentric transmit and receive quadrifilar helix antennas, each comprising two bifilar helices arranged orthogonally and excited in phase quadrature;

wherein one of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna is disposed within the cylinder defined by the other of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna;

wherein the bifilar helices comprising said transmit quadrifilar helix antenna each comprise a first filar coupled at its origin to one of the output ports on said transmit 90° hybrid coupler and a second filar coupled at its origin to ground, and wherein said first and second filar helices are electrically connected at their distal ends, and

wherein the bifilar helices comprising said receive quadrifilar helix antenna each comprise a first filar coupled at its origin to one of the input ports on said receive 90° hybrid coupler and a second filar coupled at its origin to ground, and wherein said first and second filar helices are electrically connected at their distal ends;

first disconnecting means for electrically isolating the bifilar helices of said transmit quadrifilar helix antenna from said receiver; and

second disconnecting means for electrically isolating the bifilar helices of said receive quadrifilar helix antenna from said transmitter.

13. The antenna system of claim **12**, wherein said first antenna disconnecting means comprises a plurality of switching means interposed along each electrical connection between said transmitter and said transmit quadrifilar helix antenna and wherein said second antenna disconnecting means comprises a plurality of switches interposed along each electrical connection between said receiver and said receive quadrifilar helix antenna.

14. The antenna system of claim **13**, wherein said switching means comprise PIN diodes.

15. The antenna system of claim **13**, wherein said switching means comprise gallium arsenide field effect transistors.

16. The antenna system of claim **12**, wherein said first and second 90° hybrid couplers comprise lumped element 90° hybrid couplers.

17. The antenna system of claim **12**, wherein said receive quadrifilar helix antenna defines a cylinder having a first radius, and wherein said transmit quadrifilar helix antenna defines a cylinder having a second radius, wherein said transmit quadrifilar helix antenna is disposed within the cylinder defined by said receive quadrifilar helix antenna, and wherein the bifilar helices forming said transmit quadrifilar helix antenna are radially aligned with the bifilar helices forming said receive quadrifilar helix antenna.

18. The antenna system of claim 12, wherein said transmit antenna is configured to transmit a right hand circularly polarized signal and wherein said receive antenna is configured to receive a right hand circularly polarized signal.

19. A half duplex antenna system comprising:

a receive quadrifilar helix antenna for receiving radio frequency signals in the 1525 MHz to 1559 MHz frequency band with a directivity in excess of 3 dBi for all elevation angles exceeding 45°, having four helical filars of less than 10 centimeters in length, said filars arranged orthogonally and excited in phase quadrature;

a transmit quadrifilar helix antenna for transmitting electrical signals in the 1626.5 MHz to 1660.5 MHz frequency band with a directivity in excess of 3 dBi for all elevation angles exceeding 45°, comprising four helical filars of less than 10 centimeters in length, said filars arranged orthogonally and excited in phase quadrature;

first coupling means for electrically connecting the signal from said receive quadrifilar helix antenna to said receiver;

second coupling means for electrically connecting the signal from said transmitter to said transmit quadrifilar helix antenna;

first disconnecting means for electrically isolating the bifilar helices of said transmit quadrifilar antenna from said receiver during periods of transmission; and

second disconnecting means for electrically isolating the bifilar helices of said receive quadrifilar helix antenna from said transmitter when the antenna system is operating in the receive mode; and

wherein one of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna is disposed within the cylinder defined by the other of said transmit quadrifilar helix antenna and said receive quadrifilar helix antenna.

20. The antenna system of claim 19, wherein said transmit antenna is configured to transmit a right hand circularly polarized signal and wherein said receive antenna is configured to receive a right hand circularly polarized signal.

21. The antenna system of claim 19, wherein said transmit quadrifilar helix antenna is disposed within the cylinder defined by said receive quadrifilar helix antenna.

22. The antenna system of claim 19, wherein said receive quadrifilar helix antenna is disposed within the cylinder defined by said transmit quadrifilar helix antenna.

23. The antenna system of claim 19, wherein each of said filar helices comprises a helix with a pitch angle greater than about 55 degrees and less than about 85 degrees.

* * * * *

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United States Patent [19]

Leisten

[11] **Patent Number:** 5,963,180

[45] **Date of Patent:** Oct. 5, 1999

[54] **ANTENNA SYSTEM FOR RADIO SIGNALS IN AT LEAST TWO SPACED-APART FREQUENCY BANDS**

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[73] Assignee: **Symmetricom, Inc.**, San Jose, Calif.

[21] Appl. No.: **08/690,843**

[22] Filed: **Aug. 1, 1996**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[6] **H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 343/702; 333/126

[58] **Field of Search** 343/895, 821; 333/126, 134; 455/82, 83; 370/37, 295, 297, 281

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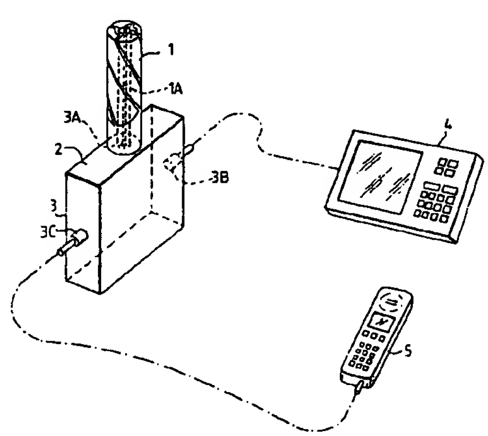
Primary Examiner—Don Wong
Assistant Examiner—Tan Ho
Attorney, Agent, or Firm—Wilson Sonsini Goodrich & Rosati

[57] **ABSTRACT**

In an antenna system for radio signals in at least two spaced-apart frequency bands above 200 MHz, a quadrifilar helical antenna having an elongate dielectric core with a relative dielectric constant greater than 5 has a conductive sleeve surrounding a proximal part of the core and a longitudinal feeder structure extending through the core to a connection with the helical antenna elements at a distal end of the core. The antenna is operated in an upper frequency band in which it exhibits a first mode of resonance characterized by current maxima at the connections of the helical elements to the feeder structure and at their junctions with the rim of the sleeve, and in a lower frequency band in which the antenna exhibits a second mode of resonance characterized by current minima in the region of the junctions of the helical elements and the sleeve rim. To permit dual mode operation, the antenna system includes an impedance-matching diplexer having filters coupled between a common port for the antenna and further ports for connection to radio signal processing equipment such as a GPS receiver and a mobile telephone operating in the two frequency bands. In the preferred embodiment, the filters and impedance matching elements are formed as microstrip elements on a single substrate.

39 Claims, 4 Drawing Sheets



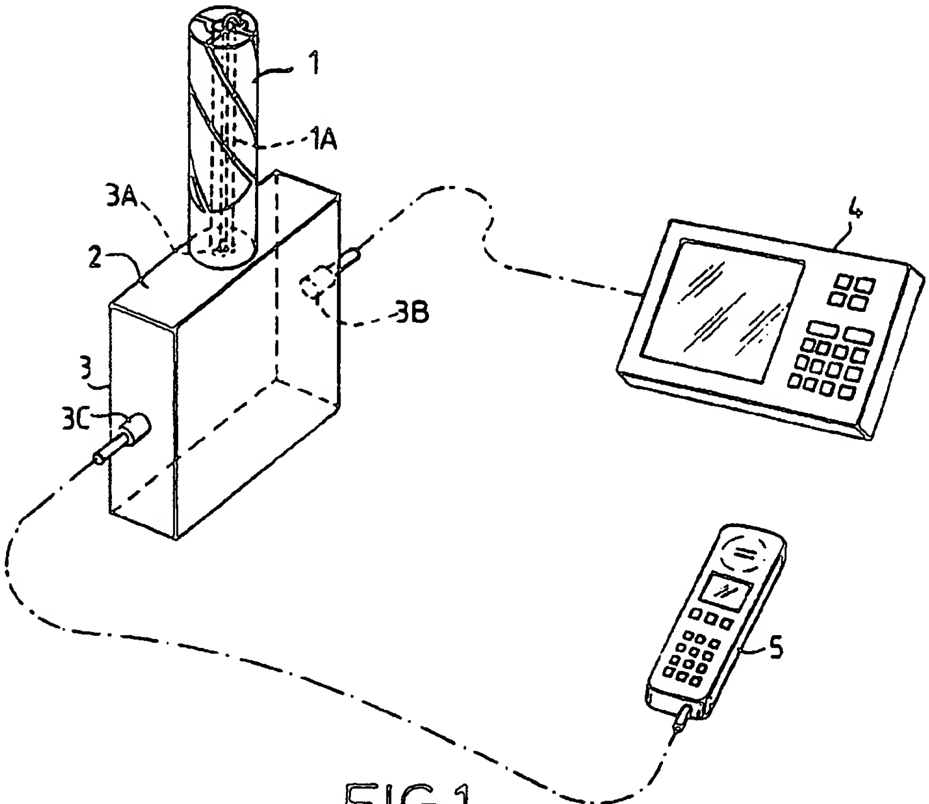
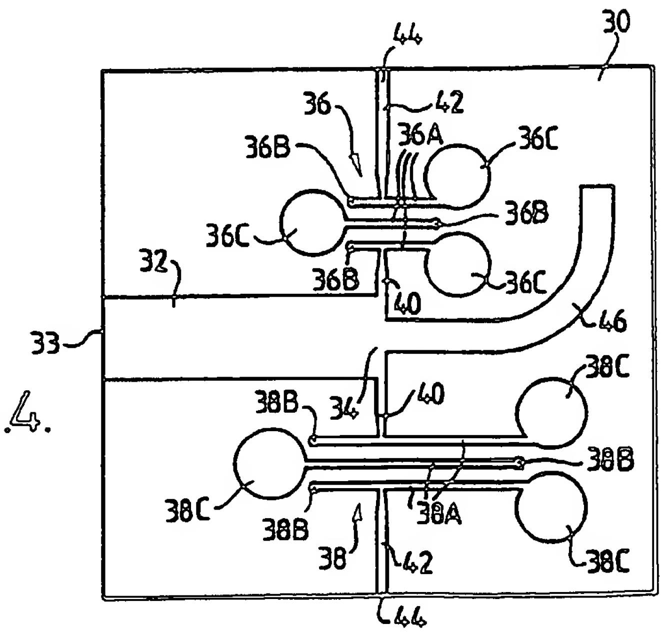

1
1A
3A
2
3B
3
3C
4
5

FIG.1.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36B
36C
36C
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36B
36C
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46
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38B
38C
38A
38B
38C
38
42
38C
44

FIG.4.

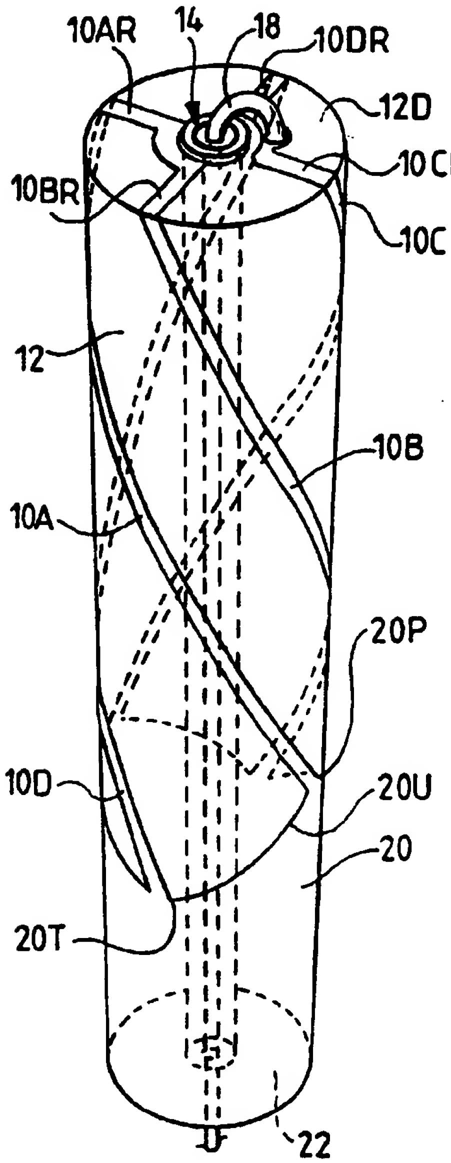
10AR
14
18
10DR
12D
10CR
10BR
10C
12
10B
10A
20P
10D
20U
20
20T
22

FIG.2.

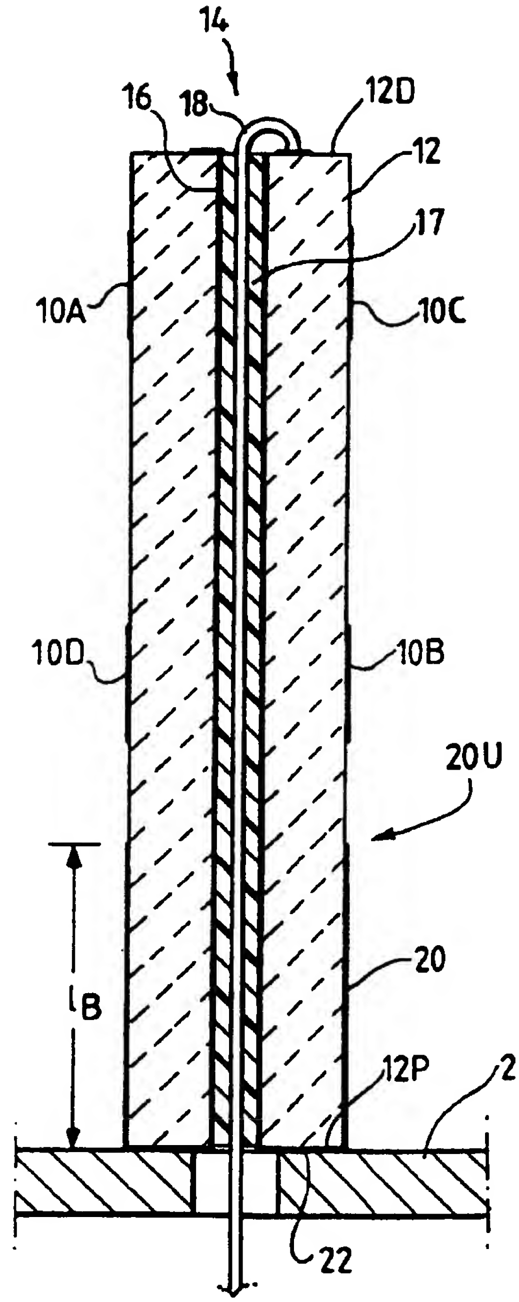
14
16
18
12D
12
17
10A
10C
10D
10B
20U
20
l_B
12P
2
22

FIG.3.

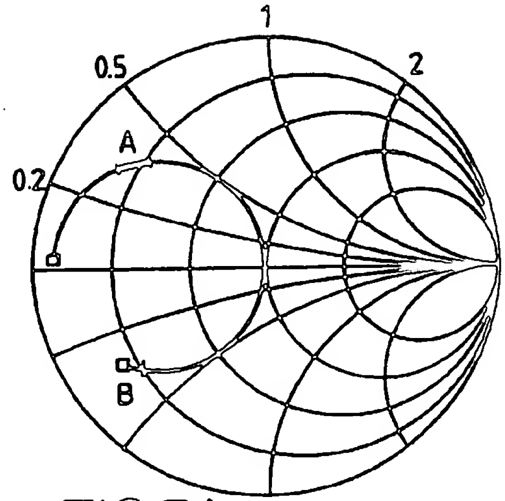

FIG.5A.

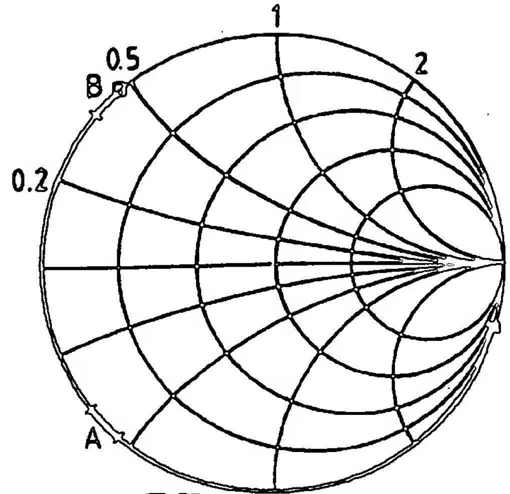

FIG.5B.

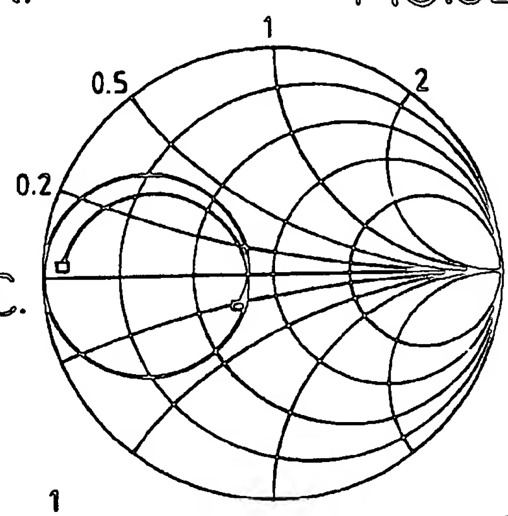

FIG.5C.

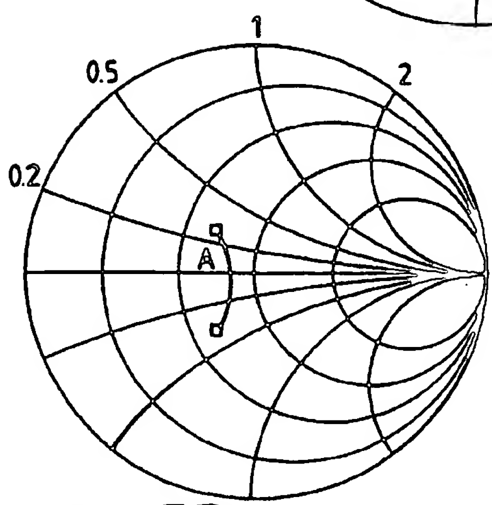

FIG.5D.

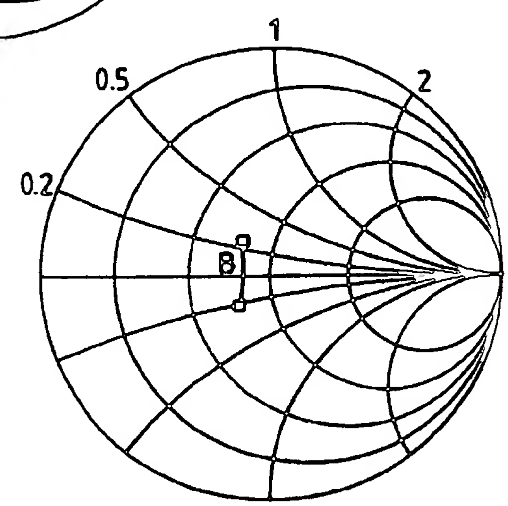

FIG.5E.

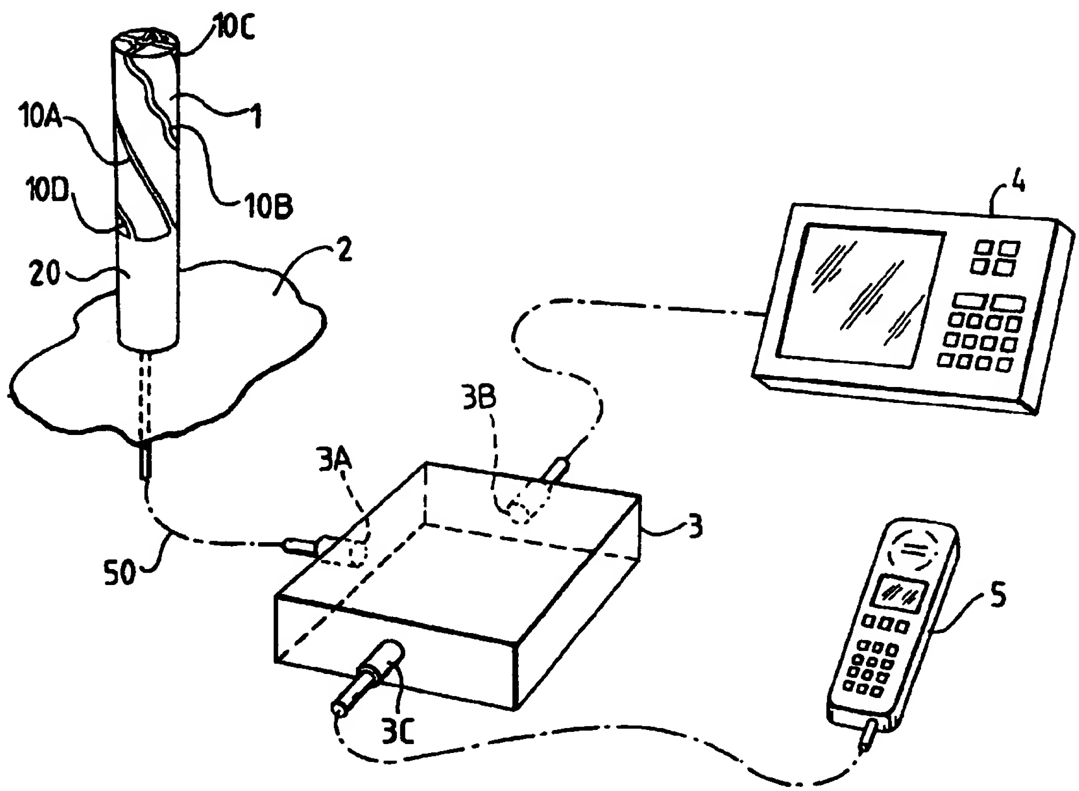

FIG.6.

ANTENNA SYSTEM FOR RADIO SIGNALS IN AT LEAST TWO SPACED-APART FREQUENCY BANDS

FIELD OF THE INVENTION

This invention relates to an antenna system including an antenna with an elongate dielectric core, elongate conductive elements on or adjacent an outer surface of a distal part of the core, and a conductive sleeve surrounding a proximal part of the core. The invention also relates to a novel use of such an antenna.

BACKGROUND OF THE INVENTION

An antenna of the above description is disclosed in the Applicant's co-pending British Patent Application which has been published under the number 2292638A, the subject matter of which is incorporated in this specification by reference. In its preferred form, the antenna of that application has a cylindrical ceramic core, the volume of the solid ceramic material of the core occupying at least 50% of the internal volume of the envelope defined by the elongate conductive elements and the sleeve, with the elements lying on an outer cylindrical surface of the core.

The antenna is particularly intended for the reception of circularly polarised signals from sources which may be directly above the antenna, i.e on its axis, or at a location a few degrees above a plane perpendicular to the antenna axis and passing through the antenna, or from sources located anywhere in the solid angle between these extremes. Such signals include the signals transmitted by satellites of a satellite navigation system such as GPS (Global Positioning System). To receive such signals, the elongate conductive elements comprise four coextensive helical elements having a common central axis which is the axis of the core, the elements being arranged as two laterally opposed pairs of elements, with the elements of one pair having a longer electrical length than the elements of the other pair. Such an antenna has advantages over air-cored antennas of robustness and small size, and over patch antennas of relatively uniform gain over the solid angle within which transmitting satellite sources are positioned.

SUMMARY OF THE INVENTION

The applicants have found that it is possible to use such an antenna in different, spaced apart, frequency bands. Accordingly, the invention provides an antenna system comprising an antenna having an elongate dielectric core with a relative dielectric constant greater than 5, at least one pair of elongate conductive elements located in a longitudinal by coextensive and laterally opposed relationship on or adjacent an outer surface of a distal part of the core, a conductive sleeve surrounding a proximal part of the core, and a longitudinal feeder structure extending through the core, the elongate conductive elements extending between distal connections to the feeder structure and a distal rim of the sleeve. Connected to the antenna is an impedance matching diplexer which has filters coupled between a common port connected to a proximal end of the antenna feeder structure, and respective further ports for connection to radio signal processing equipment operating in the two frequency bands. The filters comprise a first filter tuned to an upper frequency which lies in one of the bands and at which the antenna is resonant in a first mode of resonance, and a second filter tuned to a lower frequency which lies in the other band and at which the antenna is resonant in a second mode of resonance. The first mode of resonance may be

associated with substantially balanced feed current at the distal end of the feed structure, e.g. when the sleeve acts as a trap isolating the elongate conductive elements from a ground connection at the proximal end of the antenna, the or each pair of elongate conductive elements acting as a loop, with currents travelling around the rim of the sleeve between opposing elements of the pair. In the case of the antenna having two or more pairs of helical elements forming part of loops of differing electrical lengths, such balanced operation may typically be associated with circularly polarised signals directed within a solid angle centred on a common central axis of the helical elements. In this first mode, the antenna may exhibit current maxima at the connections of the elongate conductive elements to the feeder structure and at their junction with the rim of the sleeve.

The second mode of resonance is preferably associated with single-ended or unbalanced feed currents at the distal end of the feeder structure, with the conductive sleeve forming part of the radiating structure, as is typically the case when the antenna is resonant in a monopole mode for receiving or transmitting linearly polarised signals, especially signals polarised in the direction of a central axis of the antenna. Such a mode of resonance may be characterised by current minima in the region of the junction of the elongate elements and the rim of the sleeve.

In the first mode of resonance, the frequency of resonance is typically a function of the electrical lengths of the elongate elements, whilst the resonant frequency of the second mode of resonance is a function of the sum of (a) the electrical lengths of the elongate elements and (b) the electrical length of the sleeve. In the general case, the electrical lengths of the elongate conductive elements are such as to produce an average transmission delay of, at least approximately, 180° at a resonant frequency associated with the first mode of resonance. The frequency of the second mode of resonance may be determined by the sum of the average electrical length of the elongate conductive elements and the average electrical length of the sleeve in the longitudinal direction corresponding to a transmission delay of at least approximately 180° at that frequency.

In the preferred embodiment of the antenna system, the diplexer comprises an impedance transforming element coupled between the common port and a node to which the filters and an impedance compensation stub are connected. The transforming element, the filters, and the stub are conveniently formed as microstrip components. In such a construction, the transforming element may comprise a conductive strip on an insulative substrate plate covered on its opposite face with a conductive ground layer. The strip forms, in conjunction with the ground layer, a transmission line of predetermined characteristic impedance. Similarly, the stub may be formed as a conductive strip having an open circuit end. Although the filters may be conventional "engine block" filters, they may instead be formed of microstrip elements on the same substrate as the transforming element and the stub. These filters are desirably connected to the above-mentioned node by conductors which are electrically short in comparison to the electrical lengths of the transforming element.

The transforming element may also comprise a length of cable connected in series between the antenna feeder structure and the diplexer node, or it may comprise the series combination of such a cable and a length of microstrip between the feeder structure and the node, the cable having a characteristic impedance between the source impedance constituted by the antenna and a selected load impedance for the node.

The antenna system typically operates over two frequency bands only, but it is possible within the scope of the invention to provide a system operative in more than three spaced apart bands the antenna having a corresponding number of resonance modes.

According to a second aspect of the invention, there is provided a radio communication system comprising an antenna system as described above, a satellite positioning or timing receiver (e.g. a GPS receiver) connected to one of the further ports of the diplexer, and a cellular or mobile telephone connected to another of the further ports of the diplexer. The antenna and the filters are configured such that resonant frequencies associated with the different modes of resonance of the antenna lie respectively in the operating band of the receiver and the operating band of the telephone.

The diplexer is also the subject of a third aspect of the invention which provides a diplexer for operation at frequencies in excess of 200 MHz comprising: an antenna port; an impedance transformer in the form of a length of transmission line having one end coupled to the antenna port and the other end forming a circuit node; first and second equipment ports; a first bandpass filter tuned to one frequency and connected between the node and the first equipment port, a second bandpass filter tuned to another frequency and connected between the node and the second equipment port; and a reactance compensating element connected to the node.

The length of the transmission line forming the impedance transformer may be such as to effect a resistive impedance transformation at a frequency between the upper and the lower frequency whereby the impedances at the said node due to the transformer at the two frequencies has, respectively, a capacitive reactance component and an inductive reactance component, and wherein the stub length is such as to yield inductive and capacitive reactances respectively at the two frequencies thereby at least partly compensating for the capacitive and inductive reactances due to the transformer so as to yield at the node a resultant impedance at each of the two frequencies which is more nearly resistive than the impedances due to the transmission line.

Typically, the transmission line length is such as to provide a transmission delay of about 90° at a frequency at least approximately midway between the upper and lower frequencies.

The invention also provides, in accordance with a fourth aspect thereof, a novel use of an antenna comprising an elongate dielectric core with a relative dielectric constant greater than 5, at least one pair of elongate conductive elements located in a longitudinally coextensive and laterally opposed relationship on or adjacent an outer surface of a distal part of the core, a conductive sleeve surrounding a proximal part of the core, and a longitudinal feeder structure extending through the core, the said elongate conductive elements extending between distal connections to the feeder structure and a distal rim of the sleeve, wherein the novel use consists of operating the antenna in at least two spaced apart frequency bands, one of the bands containing a frequency at which the antenna exhibits a first mode of resonance, and another of the bands containing a frequency at which the antenna exhibits a second mode of resonance which is different from the first mode.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are described below by way of example with reference to the drawings.

In the drawings:

FIG. 1 is a diagram showing a radio communication system using an antenna system in accordance with the invention;

FIG. 2 is a perspective view of the antenna of the system of FIG. 1;

FIG. 3 is an axial cross-section of the antenna of FIG. 2, mounted on a conductive ground plane;

FIG. 4 is a plan view of a microstrip diplexer;

FIGS. 5A to 5E are Smith chart diagrams illustrating the functioning of the diplexer of FIG. 4; and

FIG. 6 is a diagram showing a radio communication system using an alternative antenna system in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1 of the drawings, a preferred antenna system in accordance with the invention for use at frequencies above 200 MHz may be used as part of radio communication equipment performing different functions. The antenna system comprises an antenna 1 in the form of an elongate cylindrical ceramic core with metallic elements plated on the outside to form a quadrifilar helical antenna with a proximal conductive sleeve forming a current trap between radiating elements of the antenna and a ground connection at its lower end. The antenna 1 is mounted on a laterally extending conductive surface 2 which, in this embodiment, is formed by a wall of the casing of a diplexer unit 3. An internal feeder structure 1A of the antenna is coupled to the diplexer unit 3 at a common port 3A thereof. The radio communication equipment includes a GPS receiver 5 connected to a first equipment port 3B of the diplexer unit 3 and a cellular telephone receiver 5 connected to a second equipment port 3C of the diplexer unit 3.

Antenna 1, as will be described below, has two modes of resonance in spaced apart frequency bands. In this example, the first mode of resonance is associated with a resonant frequency of 1.575 GHz, the antenna exhibiting a maximum in gain for circularly polarised signals at that frequency, the signals being directed generally vertically, i.e. parallel to the central axis of the antenna. This frequency is the GPS L1 frequency. The second mode of resonance of the antenna 1 in this embodiment is associated with a resonant frequency of about 860 MHz and signals linearly polarised in a direction parallel to the central axis of the antenna 1. 860 MHz is an example of a frequency lying in a cellular telephone band.

The diplexer unit 3 provides impedance matching of units 4 and 5 to the antenna 1 in its different modes of resonance, and isolates the two units 4 and 5 so that they may be operated independently, i.e. largely without the operation of one interfering with the operation of the other. The diplexer unit 3 will be described in more detail below.

The arrangement illustrated in FIG. 1 is suitable for a number of applications in which positioning information and the ability to communicate via a cellular telephone are required together. The arrangement is particularly useful for installation in an automobile, in which case the GPS receiver 4 can provide the driver with navigation information via the same antenna as a permanently installed car phone or a portable cellphone plugged into automobile wiring. The antenna 1 and diplexer unit 3, being small and robust, are particularly suited to automobile and other mobile applications. It is possible to combine the GPS receiver and the telephone within a single unit, together, if required, with the diplexer.

The antenna 1 is shown in more detail in FIGS. 2 and 3 and is as disclosed in Applicant's co-pending British Patent Application No. 9603914.4 the disclosure of which is incorporated in this specification by reference. In its preferred form, the antenna is quadrifilar having an antenna element structure with four longitudinally extending antenna elements **10A**, **10B**, **10C** and **10D** formed as metallic conductor tracks on the cylindrical outer surface of a ceramic core **12**. The core has an axial passage **14** with an inner metallic lining **16**, and the passage houses an axial feeder conductor **18**. The inner conductor **18** and the lining **16** in this case form a feeder structure **1A** for connecting a feed line to the antenna elements **10A**–**10D**. The antenna element structure also includes corresponding radial antenna elements **10AR**, **10BR**, **10CR**, **10DR** formed as metallic tracks on a distal end face **12D** of the core **12** connecting ends of the respective longitudinally extending elements **10A**–**10D** to the feeder structure. The other ends of the antenna elements **10A**–**10D** are connected to a common conductor in the form of a plated sleeve **20** surrounding a proximal end portion of the core **12**. This sleeve **20** is in turn connected to the lining **16** of the axial passage **14** by plating **22** on the proximal end face **12P** of the core **12**. The material of the core **12** occupies the major portion of the interior volume defined by the antenna elements **10A**–**10D** and the sleeve **20**.

As will be seen from FIG. **2**, the sleeve **20** has an irregular upper linking edge or rim **20U** in that it rises and falls between peaks **20P** and troughs **20T**. The four longitudinally extending elements **10A**–**10D** are of different lengths, two of the elements **10B**, **10D** being longer than the other two **10A**, **10C** by virtue of the longer elements being coupled to the sleeve **20** at the troughs of rim **20U** while the other elements **10A**, **10C** are coupled to the peaks. In this embodiment, intended for reception of circularly polarised signals when resonant in a first mode of resonance, the longitudinally extending elements **10A**–**10C** are simple helices, each executing a half turn around the axis of the core **12**. The longer elements **10B**, **10D** have a longer helical pitch than the shorter elements **10A**, **10C**. Each pair of longitudinally extending and corresponding radial elements (for example **10A**, **10AR**) constitutes a conductor having a predetermined electrical length. In the present embodiment, it is arranged that the total length of each of the element pairs **10A**, **10AR**; **10C**, **10CR** having the shorter length corresponds to a transmission delay of approximately 135° at the operating wavelength in the first mode of resonance, whereas each of the element pairs **10B**, **10BR**; **10D**, **10DR** produce a longer delay, corresponding to substantially 225°. Thus, the average transmission delay is 180°, equivalent to an electrical length of $\lambda/2$ at the operating wavelength. The differing lengths produce the required phase shift conditions for a quadrifilar helix antenna for circularly polarised signals specified in Kilgus, "Resonant Quadrifilar Helix Design", The Microwave Journal, December 1970, pages 49–54. Two of the element pairs **10C**, **10CR**; **10D**, **10DR** (i.e. one long element pair and one short element pair) are connected at the inner ends of the radial elements **10CR**, **10DR** to the inner conductor **18** of the feeder structure at the distal end of the core **12**, while the radial elements of the other two element pairs **10A**, **10AR**; **10B**, **10BR** are connected to the feeder screen formed by metallic lining **16**. At the distal end of the feeder structure, the signals present on the inner conductor **18** and the feeder screen **16** are approximately balanced so that the antenna elements are connected to an approximately balanced source or load, as will be explained below.

With the left handed sense of the helical paths of the longitudinally extending elements **10A**–**10D**, the antenna has its highest gain for right hand circularly polarised signals.

If the antenna is to be used instead for left hand circularly polarised signals, the direction of the helices is reversed and the pattern of connection of the radial elements is rotated through 90°. In the case of an antenna suitable for receiving both left hand and right hand circularly polarised signals, albeit with less gain, the longitudinally extending elements can be arranged to follow paths which are generally parallel to the axis.

As an alternative, the antenna may have helical elements of different lengths as above, but with the difference in lengths being obtained by meandering the longer elements about respective helical centre lines. In this case, the conductive sleeve is of constant axial length, as disclosed in the above-mentioned co-pending British Patent Application No. 2292638A.

The conductive sleeve **20** covers a proximal portion of the antenna core **12**, thereby surrounding the feeder structure **16**, **18**, with the material of the core **12** filling the whole of the space between the sleeve **20** and the metallic lining **16** of the axial passage **14**. The sleeve **20** forms a cylinder having an average axial length l_B as show in FIG. **2** and is connected to the lining **16** by the plated layer **22** of the proximal end face **12P** of the core **12**. In the first mode of resonance, the combination of the sleeve **20** and plated layer **22** has the effect that signals in the transmission line formed by the feeder structure **16**, **18** are converted between an unbalanced state at the proximal end of the antenna and an approximately balanced state at an axial position generally at the same axial distance from the proximal end as the average axial position of the upper linking edge **20U** of the sleeve **20**.

The preferred material for the core **12** is zirconium-titanate-based material. This material has the above-mentioned relative dielectric constant of **36** and is noted also for its dimensional and electrical stability with varying temperature. Dielectric loss is negligible. The core may be produced by extrusion or pressing.

The antenna elements **10A**–**10D**, **10AR**–**10DR** are metallic conductor tracks bonded to the outer cylindrical and end surfaces of the core **12**, each track being of a width at least four times its thickness over its operative length. The tracks may be formed by initially plating the surfaces of the core **12** with a metallic layer and then selectively removing the layer to expose the core. Removal of the metallic layer may be performed by etching according to a pattern applied in a photographic layer similar to that used for etching printed circuit boards. Alternatively, the metallic material may be applied by selective deposition or by printing techniques. In all cases, the formation of the tracks as an integral layer on the outside of a dimensionally stable core leads to an antenna having dimensionally stable antenna elements.

The antenna is preferably directly mounted on a conductive surface such as provided by a sheet metal plate **24**, as shown in FIG. **3**, with the plated proximal end surface **12P** electrically connected to the plate by, for example, soldering. In this embodiment metal plate **24** is part of the diplexer unit casing and the inner conductor **18** of the antenna for direct connection to a diplexer circuit as will be described below. The conductive lining **16** of the internal axial passage **14** of the antenna core is connected to the plated layer **22** of the proximal end face **12P** of the antenna.

From FIGS. **2** and **3** it will be appreciated that the antenna is current-fed at its distal end. The amplitude of standing wave currents in the elements **10A**–**10D** is at a maximum at the rim **20U** of the sleeve **20** where they pass around the rim so that the two pairs of elements **10A**, **10C** and **10B**, **10D** form parts of two loops which are isolated from the

grounded proximal end face **12P** of the antenna. Standing wave voltage maxima exist approximately in the middle of the elements **10A–10D**. In this mode of resonance, the radiation pattern of the antenna for right-hand circularly polarised signals is generally of cardioid form, directed distally and centred on the central axis of the core. In this quadrifilar mode, the antenna discriminates in the upward direction against left-hand polarisation, as mentioned above.

In this embodiment, the second mode of resonance is at a lower frequency and represents a mode which is quite different from the first mode of resonance. Again, the antenna is current-fed at the top, but standing wave currents decline to a minimum in the antenna elements **10A–10D** in the region of the rim **20U** of sleeve **20**. The currents are relatively high on the inside surface of the sleeve **20**, but here they do not affect the radiation pattern of the antenna. The antenna exhibits quarter wave resonance in a manner very similar to a conventional inverted monopole with a predominantly single-ended feed. There is little current flow around the rim **20U**, which is consistent with the single-ended feed. In this mode, the antenna exhibits the classic toroidal pattern of a monopole antenna with signals which are linearly polarised parallel to the central axis of the core. There is strong discrimination against horizontal polarisation.

For an antenna capable of receiving GPS signals at 1.575 GHz and cellular telephone signals in the regions of 800 to 900 MHz, the length and diameter of the core **12** are typically in the region of 20 to 35 mm and 3 to 7 mm respectively, with the average axial extent of the sleeve **20** being in the region of from 8 mm to 16 mm. A particularly preferred antenna as shown in FIGS. **2** and **3** has a core length of approximately 28.25 mm and a diameter of approximately 5 mm, the average axial length of the sleeve **20** being about 12 mm. One surprising feature of the quadrifilar mode of resonance is that the performance in this mode is tolerant of substantial variation in the average axial length of the sleeve **20** from that corresponding to a transmission delay of 90° at the respective resonant frequency, to the extent that this length can be adjusted to obtain the required resonant frequency in the second mode of resonance. However, if it is necessary to vary the axial length of sleeve **20** so far from the quarter wavelength that performance of the antenna in the quadrifilar mode deteriorates to an unacceptable degree, it is possible to insert a choke in series between the sleeve **20** and the diplexer unit (specifically the conductive surface **2** (see FIG. **1**)) to restore at least an approximately balanced current drive at the antenna distal face **12D**.

The diplexer unit **3** of FIG. **1** contains a pair of filters, a reactance compensating stub and an impedance transforming element to match the antenna to both units **4** and **5** and to isolate the signals of one with respect to the signals of the other.

In an alternative arrangement the antenna may be mounted spaced from the diplexer unit **3** as will be described below with reference to the FIG. **6**.

Referring to FIG. **4**, the diplexer unit **3** of FIG. **1** has a screening casing (as shown in FIG. **1**) enclosing a single insulative substrate plate **30** with a conductive ground layer on one side (the hidden side of plate **30** as viewed in FIG. **4**), the other side of the plate bearing conductors as shown. These conductors comprise, firstly, an impedance transforming section **32** as a conductive strip forming a transmission line section extending between one end **33**, which is connected to the antenna inner conductor, and the other end **34** which forms a circuit node. Secondly, connected to the node **34** are two bandpass filters **36, 38**. Each is constituted by three inductively coupled parallel-resonant elements, with each element being formed of a narrow inductive strip **36A, 38A** grounded at one end by a plated-through hole **36B, 38B** and having a capacitor plate **36C, 38C** at the opposite end, forming a capacitor with the ground conductor on the other surface of the substrate. In the case of each filter **36, 38**, the inductive strip **36A, 38A** nearest the node **34** is connected to the latter by an electrically short tapping conductor **40**, which is tapered to effect a further impedance transformation. In each case, the inductive strip furthest from the node **34** is coupled to tapping lines **42** (which are also tapered near the filter) coupling the filter to respective equipment connections **44**.

As will be apparent from the different sizes of filters **36, 38**, they are tuned to different frequency bands, in fact the two bands corresponding to the two modes of resonance of the antenna **1**.

Impedance matching at both resonant frequencies is achieved by the combination of the transforming section **32** and an open-circuit ended stub **46** extending from node **34** as shown in FIG. **4**.

Transforming section **32** is dimensioned to have a characteristic transmission line impedance Z_o given by:

$$Z_o=\sqrt{(Z_S Z_L)}$$

where Z_S is the characteristic impedance of the antenna **1** at resonance, and Z_L is a selected load impedance for the node **34** to suit filters **36** and **38**. The length of the transforming section **32** is arranged to correspond to a transmission delay of about 90° at a frequency approximately midway between the two frequency bands corresponding to the first and second modes of resonance, in this case approximately 1.22 GHz. The effect of the transforming section **32** at different frequencies is illustrated by the Smith chart of FIG. **5A** which represents the impedance seen at node **34** due to the transforming section **32** in the absence of the stub **46** over a range of frequencies from 0.1 to 1.6 GHz. Sections A and B of the curve indicate the two frequency bands centred on 860 MHz and 1.575 GHz, and it will be seen that a resistive impedance is obtained at the centre of the chart, at a frequency between the two bands, as mentioned above. The effect of stub **46** (see FIG. **4**) is now considered with reference to the Smith chart of FIG. **5B**. At low frequencies, the impedance presented solely by stub **46** at node **34** is relatively high, as is evident from the end of the curve in FIG. **5B** being close to the right-hand side of the chart. With increasing frequency, the impedance passes around the perimeter of the chart through a zero impedance point corresponding to a frequency approximately midway between the frequency bands A and B due to the selected lengths of stub **46**.

Comparing FIGS. **5A** and **5B**, it will be noted that the impedance at node **34** due to transforming section **32** in band A has an inductive reactance component, whilst the impedance in band B has a capacitive reactance component. In the Smith charts, the curves emanating from the right-hand end are lines of constant reactance. From FIG. **5B**, it will be seen that the stub **46** is so dimensioned that the reactance component of the impedance presented solely by the stub **46** at node **34** in band A is capacitive and at least approximately equal to the inductive reactance in band A shown in FIG. **5A**. Similarly, the impedance due to stub **46** in band B has an inductive reactance component which is at least approximately equal in magnitude to the capacitive reactance component in band B as shown in FIG. **5A**.

Referring now to FIG. 5C, the trace of the impedance at node 34 due to the combination of the transforming section 32 and the stub 46 follows a loop which begins, at low frequency, at an impedance corresponding to the source impedance at the port 3A indicated in FIG. 1. With increasing frequency, the trace follows a loop which crosses the resistance line twice. The first crossing corresponds approximately to the centre of band A as shown by the curve in FIG. 5D which is simply a portion of the curve shown in FIG. 5C corresponding to frequency band A, whilst the second crossing of the resistance line represents the approximate centre of band B, as shown by the curve of FIG. 5E which is also a portion of the curve shown in FIG. 5C. In this way, the elements of the diplexer perform a good impedance match of the antenna 1 to the filters 36, 38 in both frequency bands A and B, with the reactances of the stub 46 compensating at least partly for the reactances due to the transforming section. Each filter presents a relatively high impedance at the frequency of the other filter, thereby providing isolation between signals in the two bands.

In the example shown in FIG. 1, this isolation is used to isolate a GPS receiver 4 from cellular telephone signals fed to and from a telephone unit 5.

An alternative antenna system is shown in FIG. 6. In this case, the antenna 1 is mounted on a laterally extending conductive surface 2 which, rather than being part of a diplexer casing, instead forms part of another metallic structure, such as a vehicle body. The antenna is coupled through a hole in the surface 2 by means of a feed cable 50 coupled to the common port 3A of a diplexer 3, the latter being similar to the diplexer of the embodiment described above with reference to FIG. 1. Feed cable 3 has an inner conductor coupled to the axial inner conductor of the antenna 1 and an outer shield which is connected to the plated proximal face of the antenna. At the diplexer end of cable 50, the shield is connected to the diplexer casing and directly or indirectly to the ground plane of a microstrip diplexer board within the casing, similar to that show in FIG. 4.

Unless the characteristic impedance of feed cable 50 is the same as the source impedance represented by the antenna 1, the cable 50 acts as an impedance transforming element. The extent to which this occurs depends on the length of the cable and the value of the characteristic impedance, and the microstrip diplexer element is correspondingly altered such that the required total impedance transformation occurring between the antenna 1 and the node 34 of the diplexer (see FIG. 4) has the same effect as the transforming section 32 of the diplexer of the first embodiment described above, and shown in FIGS. 1 and 4. Thus, the electrical length of the combination of cable 50 and the impedance transforming section of the diplexer 3 is about 90° at a frequency approximately midway between the two frequency bands corresponding to the first and second modes of resonance. It is possible, therefore, for the microstrip diplexer to be as shown in FIG. 4 but with impedance transforming section 32 having a much reduced length, or being formed at least in part by a microstrip section having a characteristic impedance equal to the load impedance at load 34. Typically, feed cable 50 has a characteristic impedance of 10 ohms. The system of FIG. 6 uses the alternative antenna mentioned above, in that, while having four helical elements which are generally coextensive and coaxial, two oppositely disposed elements follow meandered paths to achieve the differences in length which bring about the required phase shift conditions for a quadrifilar helix antenna for circularly polarised signals. The meandering of one pair of elements takes the place of the irregular rim of the sleeve 20 shown in FIG. 2, so that in this embodiment sleeve 20 has a circular upper edge which extends around the antenna core at a constant distance from the proximal end.

What is claimed is:

1. An antenna system for radio signals in at least two spaced-apart frequency bands comprising:

an antenna having an elongate dielectric core with a relative dielectric constant greater than 5, at least one pair of elongate conductive elements located in a longitudinally coextensive and laterally opposed relationship on or adjacent an outer surface of a distal part of the core, a conductive sleeve surrounding a proximal part of the core, and a longitudinal feeder structure extending through the core, said elongate conductive elements extending between distal connections to the feeder structure and a distal rim of the sleeve, wherein the antenna is resonant in a first mode of resonance at an upper frequency lying in one of said two frequency bands and in a second mode of resonance at a lower frequency lying in the other of said two frequency bands; and

an impedance matching diplexer which has filters coupled between a common port connected to a proximal end of the feeder structure and respective further ports for connection to radio signal processing equipment operating in the two frequency bands, the filters comprising a first filter tuned to the upper frequency, and a second filter tuned to the lower frequency.

2. An antenna system according to claim 1, wherein the first and second modes of resonance are associated respectively with substantially balanced and single-ended feed currents at the distal end of the feeder structure.

3. An antenna system according to claim 1, wherein the first mode of resonance is characterised in operation of the antenna at the upper frequency by current maxima at the connections of the elongate conductive elements to the feeder structure, and at their junctions with the rim of the sleeve, the sleeve acting as a trap which isolates the elongate conductive elements from ground, and wherein the second mode of resonance is characterised in operation of the antenna at the lower frequency by current minima in the region of the junctions of the elongate elements and the rim of the sleeve.

4. An antenna system according to claim 3, wherein the upper frequency is a function of the electrical length of the elongate elements, whilst the lower frequency is a function of the sum of the electrical length of the elongate elements and the electrical length of the sleeve.

5. An antenna system according to claim 4, wherein the average electrical length of the elongate conductive elements is at least approximately 180° at the upper frequency, and the sum of the average electrical length of the elongate conductive elements and the average electrical length of the sleeve in the longitudinal direction of the antenna is at least approximately 180° at the lower frequency.

6. An antenna system according to claim 5, wherein the elongate conductive elements consist of two pairs of helical elements, the elements of each pair being diametrically opposed on the cylindrical outer surface of the core with those of one pair being longer than those of the other pair, whereby the first mode of resonance is a circular polarisation mode associated with circularly polarised signals directed along the central axis of the core, and the second mode of resonance is a linear polarisation mode associated with signals polarised in the direction parallel to the core axis.

7. An antenna system according to claim 1, wherein the core is a solid cylindrical body of ceramic material with an

axial bore containing the feeder structure, and wherein the elongate conductive elements are helical.

8. An antenna system according to claim 1, wherein the diplexer comprises an impedance transforming element coupled between the common port and a node to which the filters and an impedance compensation stub are connected.

9. An antenna system according to claim 8, wherein the impedance transforming element, the filters and the stub are formed as microstrip components, the transforming element comprising a conductive strip forming a transmission line of predetermined characteristic impedance, and the stub comprising a conductive strip having an open circuit end.

10. An antenna system according to claim 8, wherein the filters are microstrip bandpass filters connected to the node by conductors which are electrically short in comparison to the electrical length of the transforming element.

11. A radio communication system comprising an antenna system according to claim 1, a satellite signal receiver connected to one of said further ports, and a mobile telephone connected to another of said further ports, the antenna and the filters being configured such that said one of the upper and lower frequencies lies in the operating band of the receiver and said other of the upper and lower frequencies lies in the operating band of the mobile telephone.

12. An antenna comprising:

an elongate core with a relative dielectric constant greater than 5;

at least one pair of elongate conductive elements located in a longitudinally coextensive and laterally opposed relationship on or adjacent an outer surface of a distal part of the core;

a conductive sleeve surrounding a proximal part of the core; and

a longitudinal feeder structure extending through the core, said elongate conductive elements extending between distal connections to the feeder structure and a distal rim of the sleeve,

wherein the elongate conductive elements are adapted such that the antenna operates in at least two spaced apart frequency bands, one of the bands containing a first frequency at which the antenna exhibits a first mode of resonance and which corresponds substantially to the frequency of signals transmitted in a satellite positioning service, and another of the bands containing a second frequency at which the antenna exhibits a second mode of resonance which is different from the first mode, the frequency of the second resonance corresponding substantially to a frequency used for mobile telephone signals.

13. Use of an antenna according to claim 12, wherein the first and second modes of resonance are associated respectively with a substantially balanced feed current and a single-ended feed current at the distal end of the feeder structure.

14. Use of an antenna according to claim 12, wherein the frequency of the first mode is determined by the electrical lengths of the elongate conductive elements, whereas the frequency of the second mode is determined by the sum of the average electrical length of the elongate conductive elements and the average electrical length of the sleeve.

15. Use of an antenna according to claim 12, wherein the first mode of resonance is associated with circularly polarised signals, whereas the second mode of resonance is associated with signals linearly polarised in the longitudinal direction of the antenna.

16. An antenna system for radio signals in at least two spaced-apart frequency bands comprising:

an antenna having a solid elongate dielectric core, at least one elongate conductive element on or adjacent an outer surface of a distal part of the core, a conductive sleeve surrounding a proximal part of the core, and a longitudinal feeder structure extending through the core, wherein the said elongate conductive element extends between a distal connection to the feeder structure and a distal rim of the sleeve, and the sleeve is proximally coupled to the feeder structure; and wherein the antenna is resonant in a first mode of resonance at an upper frequency lying in one of said two frequency bands and in a second mode of resonance at a lower frequency lying in the other of said two frequency bands; and

a coupling stage having a common signal line associated with the feeder structure, at least two further signal lines for connection to radio signal processing equipment operating in the said frequency bands and, connected between the feeder structure and the further signal lines, an impedance matching section and a signal directing section, wherein the signal directing section is arranged to couple together the common signal line and one of the two further signal lines for signals which lie in one of said frequency bands, and to couple together the common signal line and the other of the two further signal lines for signals which lie in the other of said frequency bands.

17. An antenna system according to claim 16, wherein the coupling stage is a diplexer which has filters coupled between the common signal line and the further signal lines, the filters including a first filter associated with one of said two further signal lines and tuned to said upper frequency and a second filter associated with the other of said two further signal lines and tuned to said lower frequency.

18. An antenna system according to claim 17, wherein the diplexer comprises an impedance transforming element coupled between the common signal line and a node to which the filters and an impedance compensation stub are connected.

19. An antenna system according to claim 18, wherein the impedance transforming element, the filters and the stub are formed as microstrip components, the transforming element comprising a conductive strip forming a transmission line of predetermined characteristic impedance, and the stub comprising a conductive strip having an open circuit end.

20. An antenna system according to claim 18, wherein the filters are microstrip bandpass filters connected to the node by conductors which are electrically short in comparison to the electrical length of the transforming element.

21. An antenna system according to claim 16, wherein the antenna has at least one pair of said elongate conductive elements and is adapted such that said elongate conductive element and said sleeve act jointly to define said upper and lower frequencies.

22. An antenna system according to claim 21, wherein at least one of said resonant frequencies is defined by the sum of the length of the sleeve and the length of said elongate conductive element.

23. An antenna system according to claim 16, wherein the sleeve and the feeder structure together act as a balun in at least one of the modes.

24. An antenna system according to claim 16, wherein the first and second modes of resonance are associated respectively with substantially balanced and single-ended feed currents at the distal end of the feeder structure.

25. An antenna system according to claim 16, wherein the dielectric core has an outer surface defining an interior

volume at least half of which is occupied by a solid insulative material having a relative dielectric constant greater than 5, the antenna having a least one pair of said elongate conductive elements located in a longitudinally co-extensive and laterally opposed relationship on the outer surface of the distal part of the core each with respective distal connections to the feeder structure and the distal rim of the sleeve, and wherein the common signal line of the coupling stage is coupled to a proximal end of the feeder structure.

26. An antenna system according to claim **25**, wherein the first mode of resonance is characterised in operation of the antenna at the upper frequency by current maxima at the connections of the elongate conductive elements to the feeder structure, and at their junctions with the rim of the sleeve, the sleeve acting as a trap which isolates the elongate conductive elements from ground, and wherein the second mode of resonance is characterised in operation of the antenna at the lower frequency by a voltage minimum at or adjacent the coupling of the sleeve to the feeder structure.

27. An antenna system according to claim **26**, wherein the upper frequency is a function of the electrical length of the elongate element, whilst the lower frequency is a function of the sum of the electrical length of the elongate element and the electrical length of the sleeve.

28. An antenna system according to claim **27**, wherein the average electrical length of the elongate conductive elements is at least approximately 180° at the upper frequency, and the sum of the average electrical length of the elongate conductive elements and the average electrical length of the sleeve in the longitudinal direction of the antenna is at least approximately 180° at the lower frequency.

29. An antenna system according to claim **28**, wherein the elongate conductive elements consist of two pairs of helical elements, the elements of each pair being diametrically opposed on the cylindrical outer surface of the core with those of one pair being longer than those of the other pair, whereby the first mode of resonance is a circular polarisation mode associated with circularly polarised signals directed along the central axis of the core, and the second mode of resonance is a linear polarisation mode associated with signals polarised in the direction parallel to the core axis.

30. An antenna system according to claim **16**, wherein said at least one elongate conductive element and the sleeve, together with the core, constitute a unitary structure having a plurality of different modes of resonance which are characterised by standing wave maxima and minima of differing patterns within the unitary structure.

31. An antenna system according to claim **30**, wherein each of said patterns of standing wave maxima and minima exist on the outer surface of the core between the distal connection of the at least one elongate conductive element to the feeder structure and proximal coupling of the sleeve to the feeder structure.

32. An antenna system according to claim **16**, wherein the core is a solid cylindrical body of ceramic material with an axial bore containing the feeder structure, and wherein the elongate conductive elements are helical.

33. A radio communication system comprising an antenna system according to claim **16**, wherein the antenna system has a pluarity of ports a satellite positioning or timing receiver connected to one of the said ports, and cellular or mobile telephone circuitry connected to another of said ports, the antenna and the filters being configured such that the one of the upper and lower frequencies lies in the operating band of the receiver and the other of the upper and lower frequencies lies in the operating band of the mobile telephone circuitry.

34. A radio communication apparatus comprising an antenna and, connected to the antenna, radio communication circuit means operable in at least two radio frequency bands, wherein the antenna comprises an elongate dielectric core, a feeder structure which passes through the core substantially from one end to the other end of the core, and, located on or adjacent the outer surface of the core, the series combination of at least one elongate conductive antenna element and a conductive trap element which has a grounding connection to the feeder structure in the region of the said one end of the core, the or each antenna element being coupled to a feed connection of the feeder structure in the region of the said other end of the core, and wherein the radio communication circuit means have two parts operable respectively in a first and a second of the radio frequency bands and each associated with respective signal lines for conveying signals between the antenna feeder structure and the respective circuit means part, the antenna being resonant in a first resonance mode in the first frequency band and in a second resonance mode in the second frequency band.

35. An apparatus according to claim **34**, wherein the first and second modes of resonance are associated respectively with substantially balanced and single-ended feed currents at the feed connection.

36. An apparatus according to claim **34**, wherein the conductive elements of the series combination, and the dielectric core, constitute a unitary structure having a plurality of different modes of resonance which are characterised by standing wave maxima and minima of differing patterns within the unitary structure.

37. An apparatus according to claim **36**, wherein the antenna is formed without lumped filtering components dividing the antenna into separately resonant parts, and wherein all conduction paths of the unitary structure are available to currents at all frequencies, the resonant paths at each resonant frequency being the preferred paths at that frequency.

38. An apparatus according to claim **34**, wherein the core is a rod of solid dielectric material having a relative dielectric constant greater than 5, and wherein the said series combination comprises at least one pair of longitudinally coextensive elongate antenna elements and the trap element is a conductive sleeve encircling the rod on the surface of the rod.

39. An antenna comprising:

an elongate core with a relative dielectric constant greater than 5;

at least one pair of elongate conductive elements located in a longitudinally coextensive and laterally opposed relationship on or adjacent an outer surface of a distal part of the core;

a conductive sleeve surrounding a proximal part of the core; a longitudinal feeder structure extending through the core, said elongate conductive elements extending between distal connections to the feeder structure and a distal rim of the sleeve;

wherein the elongate conductive elements are adapted such that the antenna operates in at least two spaced apart frequency bands, one of the bands containing a first frequency at which the antenna exhibits a first mode of resonance, said first frequency being 1.575 GHz, and another of the bands containing a second frequency at which the antenna exhibits a second mode of resonance which is different from the first mode, said second frequency being in the band of from 800 to 900 MHz.

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United States Patent [19]

Robinson

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[45] **Date of Patent:** **Nov. 2, 1999**

[54] **SELF-DEPLOYING HELICAL STRUCTURE**

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[73] Assignee: **Orbital Sciences Corporation**, Dulles, Va.

[21] Appl. No.: **08/896,728**

[22] Filed: **Jul. 18, 1997**

Related U.S. Application Data

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[51] **Int. Cl.**[6] **H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 16/226

[58] **Field of Search** 343/881, 895, 343/897; 16/226, 277; 29/173

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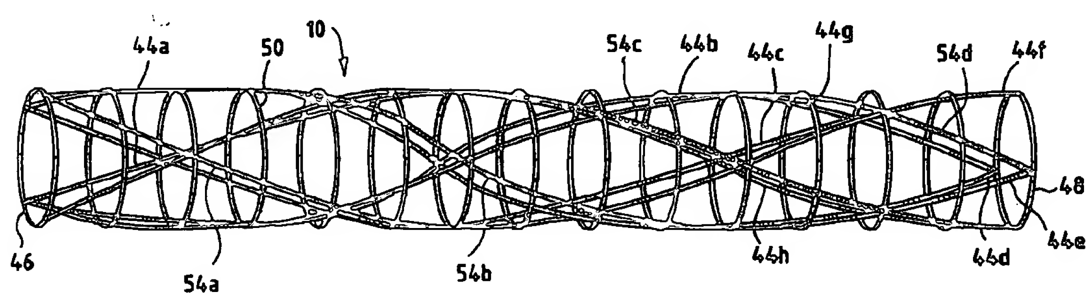
Primary Examiner—Don Wong
Assistant Examiner—Tho Phan
Attorney, Agent, or Firm—Jenner & Block

[57] **ABSTRACT**

A helical antenna structure is deformable and capable of being stowed in a small volume. At deployment, the helical antenna structure uses the stored strain energy in its resilient helices to revert to its original shape without the use of any outside force. Multiple antenna structures can be linked using a plurality of resilient lenticular shaped hinges.

16 Claims, 10 Drawing Sheets



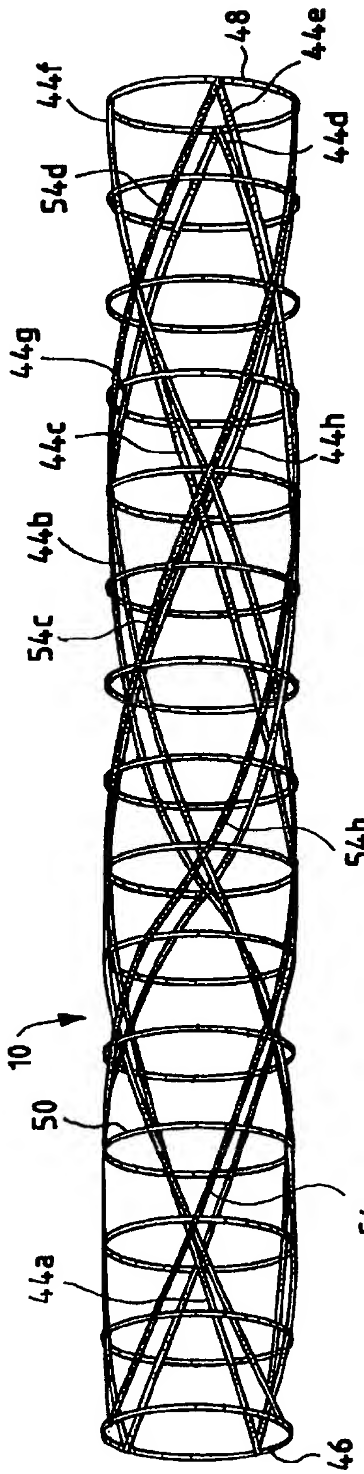


Fig. 1

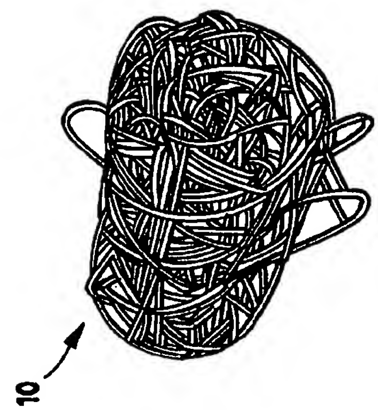


Fig. 3

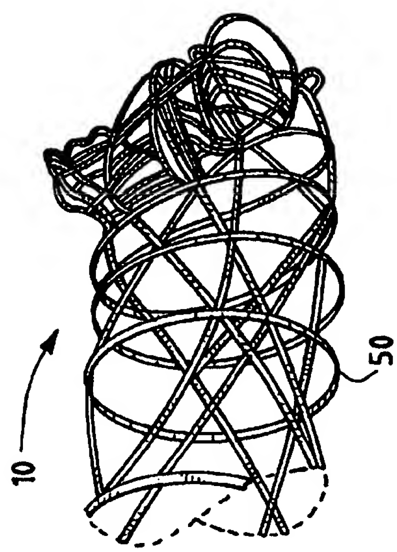


Fig. 2

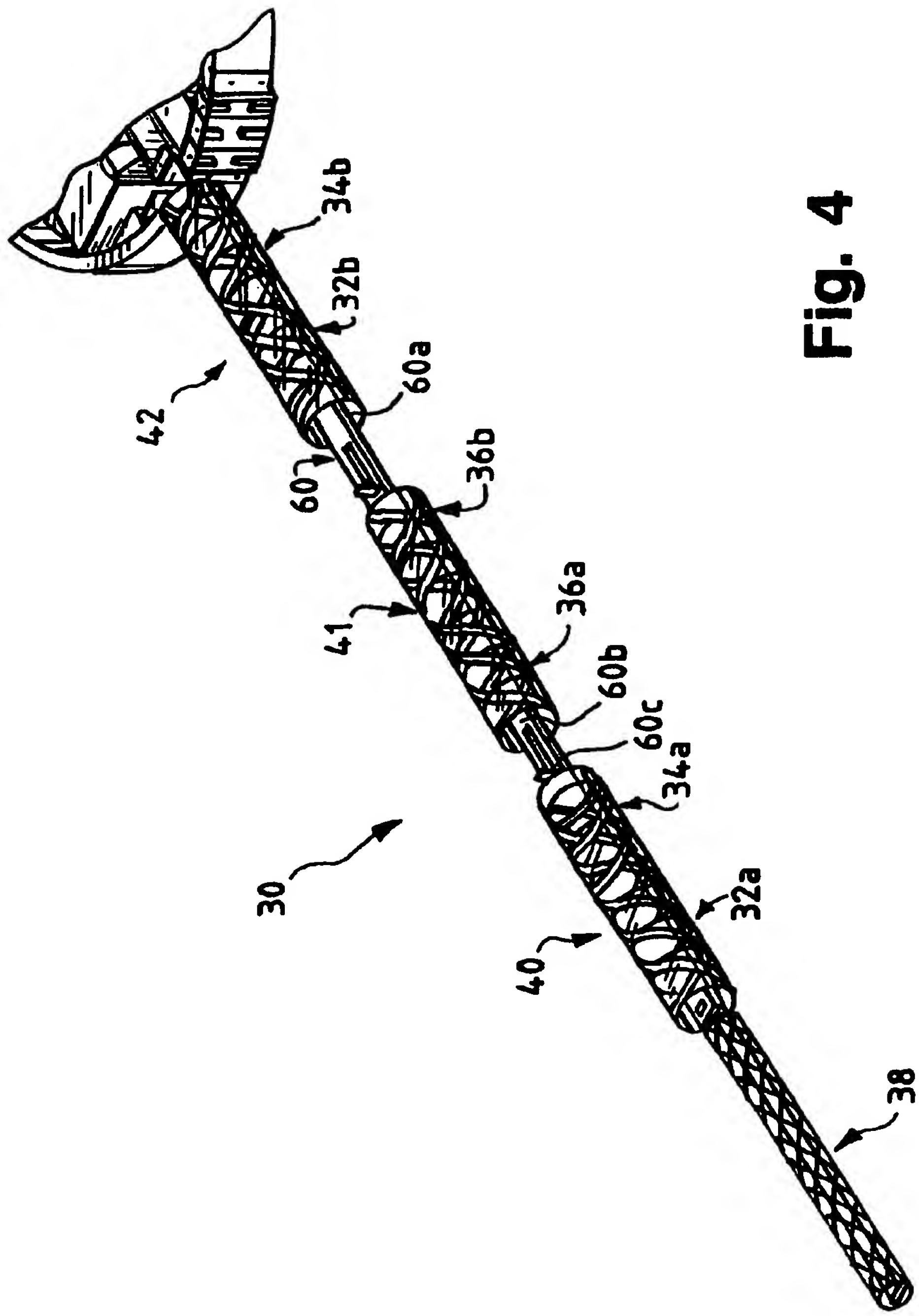
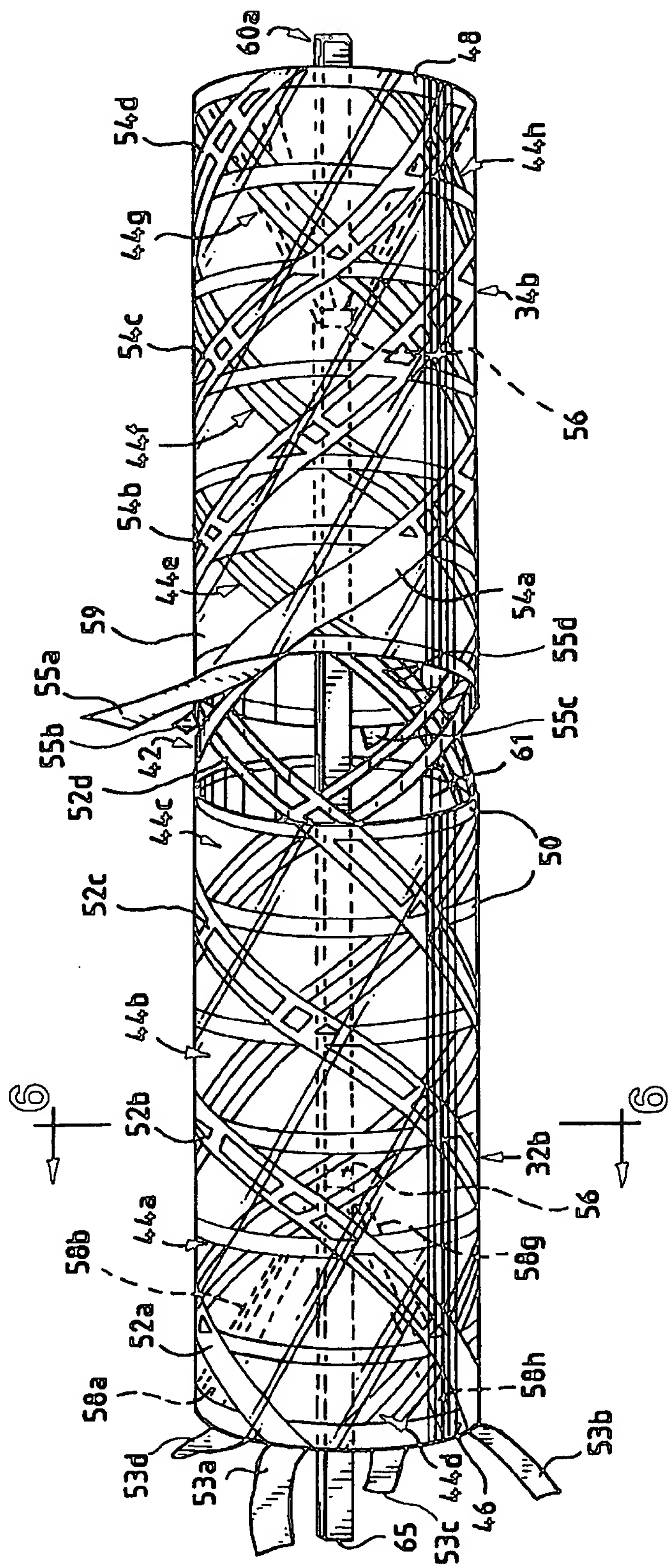


Fig. 4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48
54d
44h
44g
34b
54c
56
44f
54b
44e
54a
59
55d
55a
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55b
61
42
52d
44c
50
52c
44b
6
6
52b
32b
56
44a
58b
58g
52a
58a
58h
53d
53b
53a
44d
46
53c
65

Fig. 5

Fig. 6

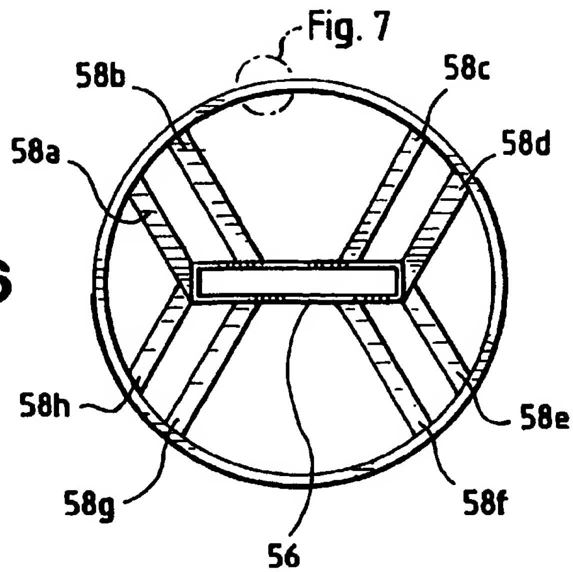
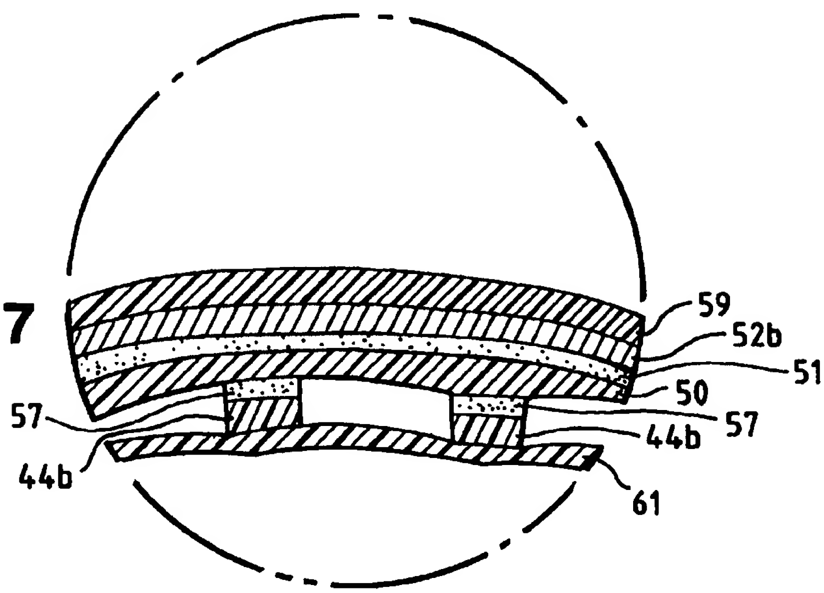


Fig. 7
58b
58c
58a
58d
58h
58e
58g
58f
56

Fig. 7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52b
51
50
57
57
44b
44b
61

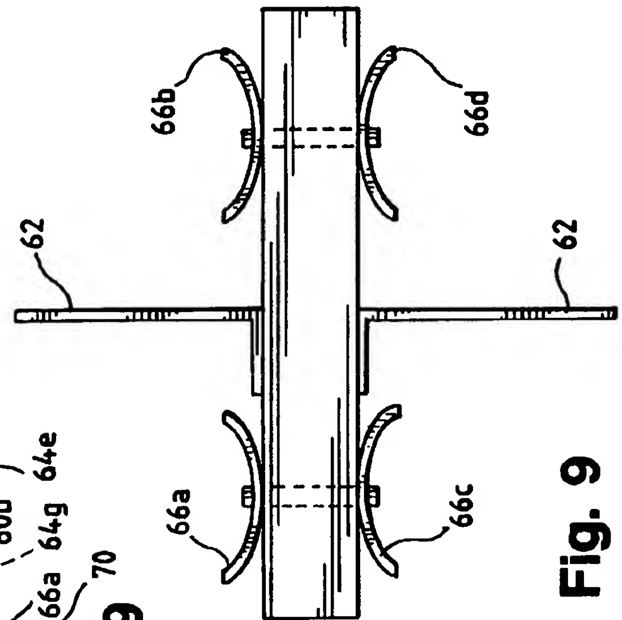
66b
66d
62
62
66a
66c

Fig. 9

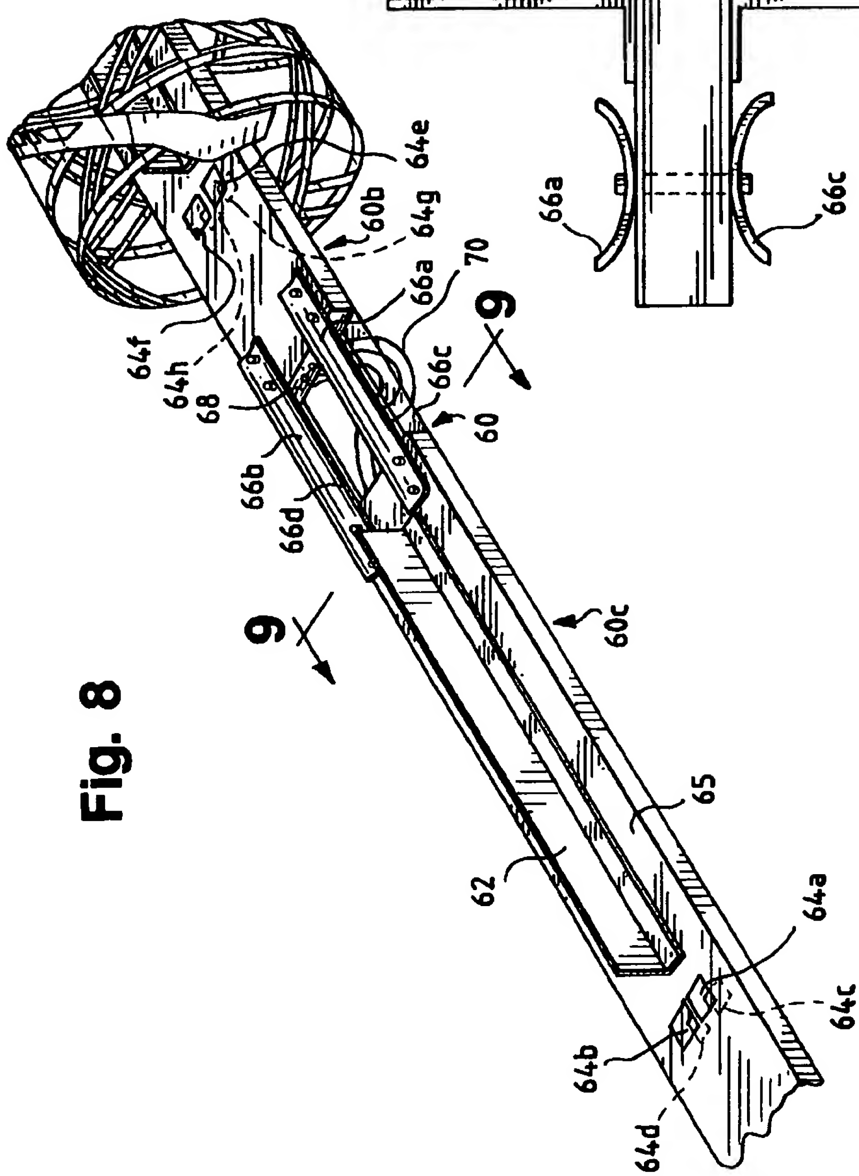
64e
60b
64g
70
66a
9
66c
60
64f
64h
68
66b
66d
9
60c
65
62
64a
64c
64b
64d

Fig. 8

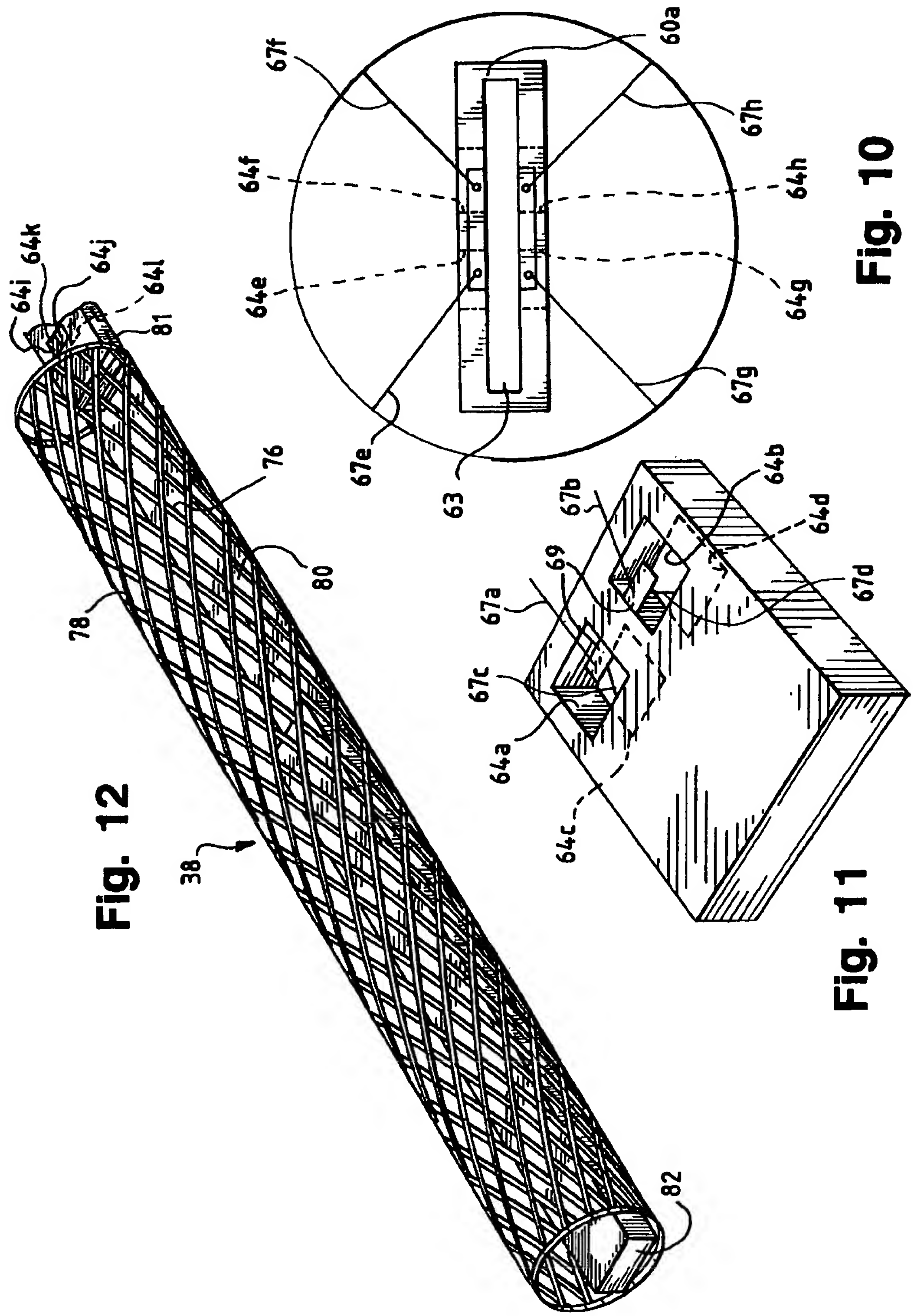

Fig. 10

Fig. 11

Fig. 12

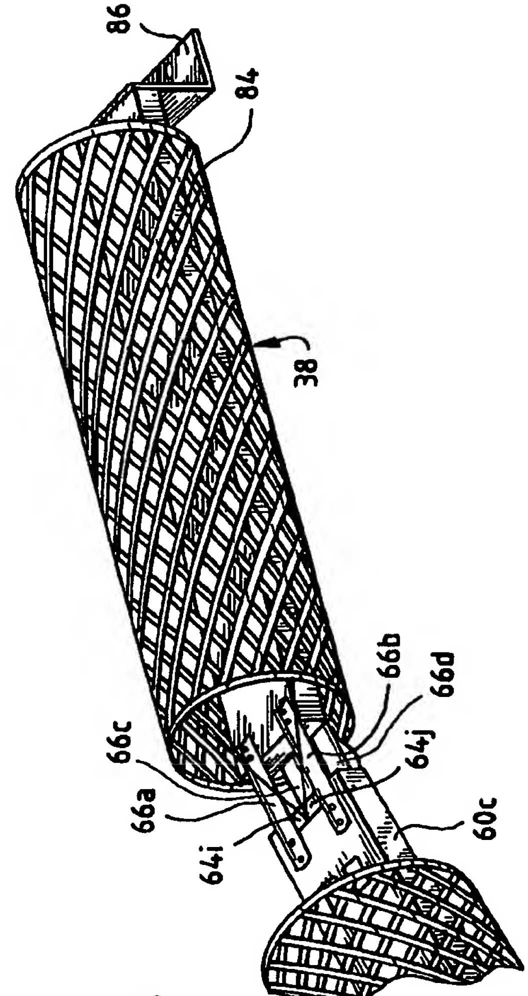
86
84
38
66b
66d
66c
64j
66a
60c
64i

Fig. 13

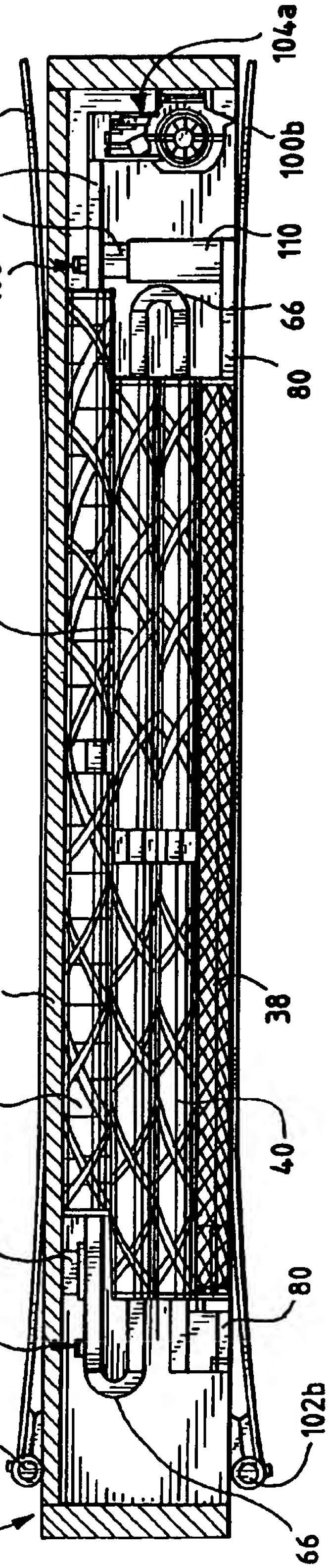
104a
100a
100b
60
112
110
106
66
80
41
108
38
42
40
72
80
106
102a
102b
66
114

Fig. 14

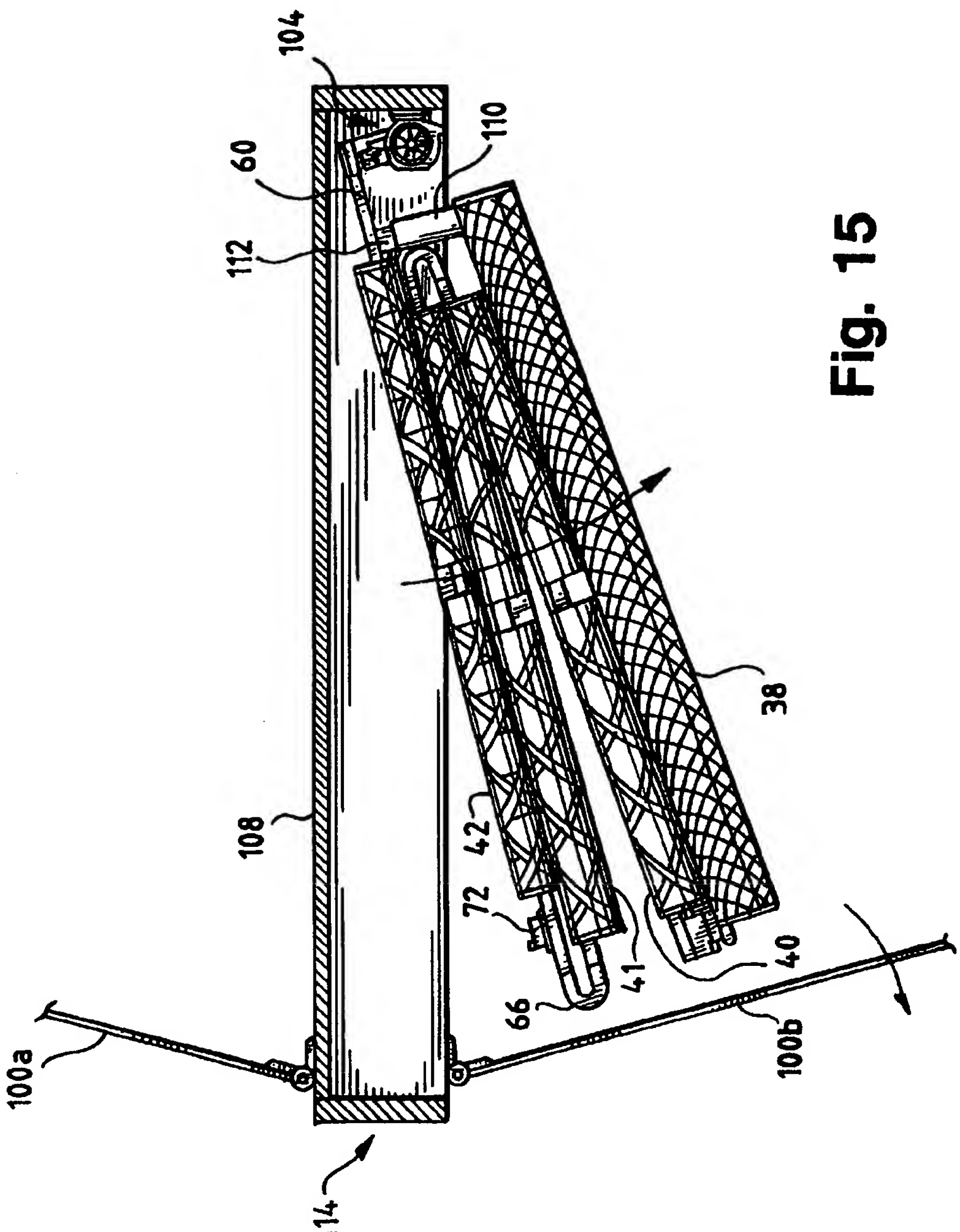

Fig. 15

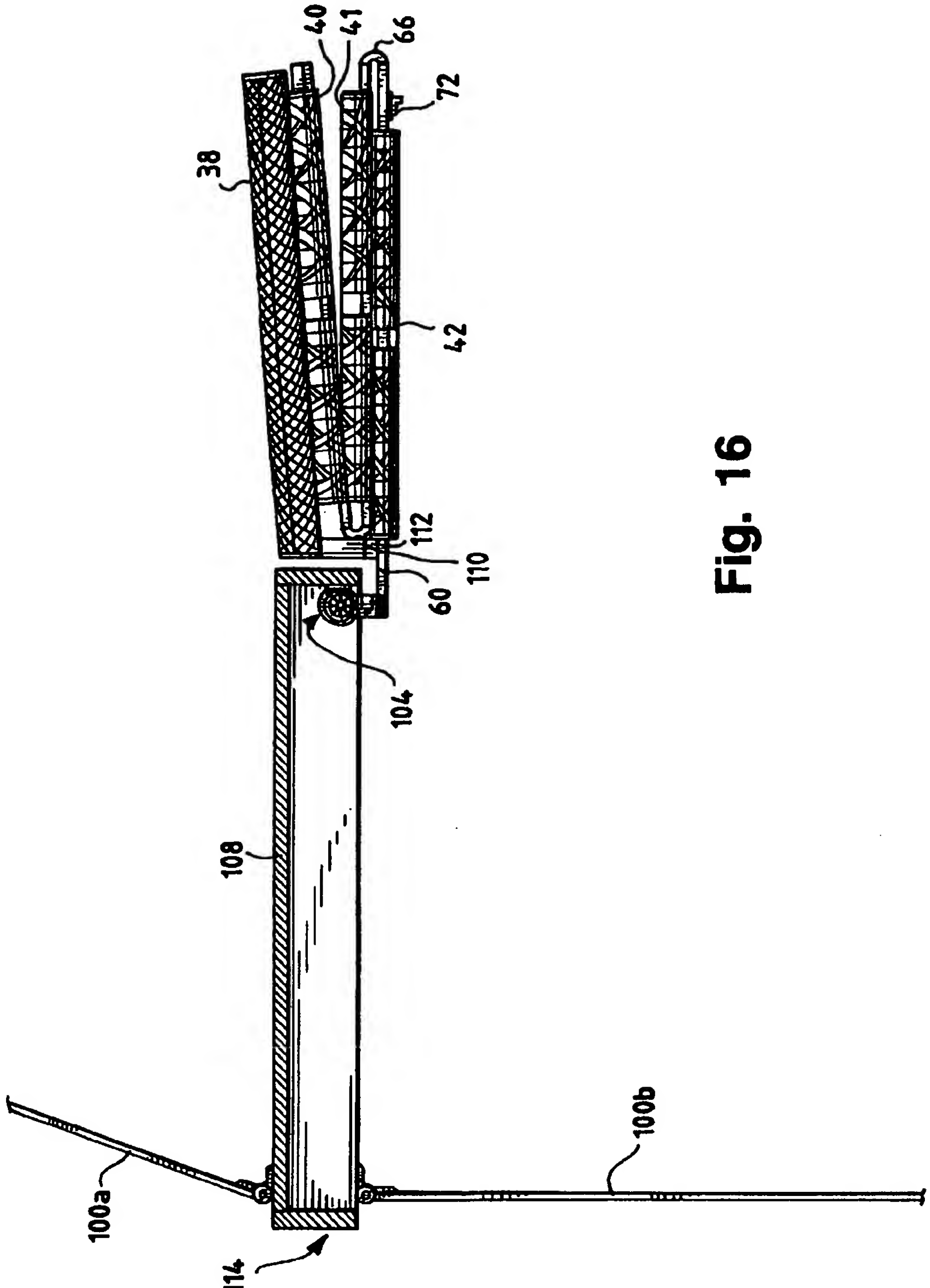

Fig. 16

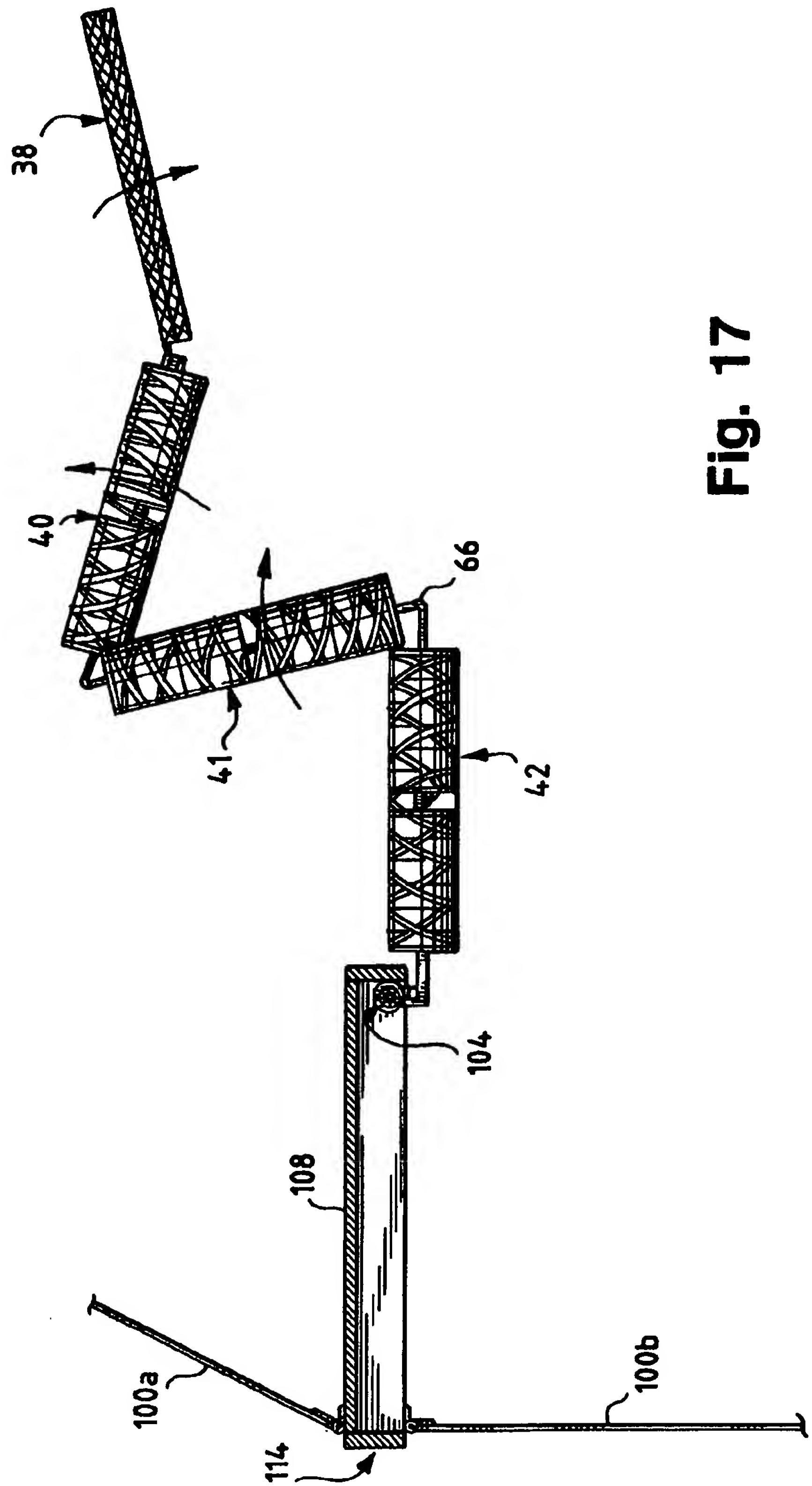

Fig. 17

SELF-DEPLOYING HELICAL STRUCTURE

This application is a continuation of application Ser. No. 08/561,261, filed Nov. 13, 1995 which is a cont of Ser. No. 08/192,324 filed Feb. 4, 1994.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to self-deploying, helical structures and more particularly to a self-deploying helical structure employed as an antenna.

2. Description of the Related Art

Helical antennae are generally well-known in the art. While some helical antennae are designed to be permanent and stationary in their operating configuration, it is often desirable to have an antenna capable of being transported and then deployed into its extended operating configuration. Thus, many attempts have been made to design helical antennae capable of being collapsed and transported and then deployed into the extended operating configuration.

For example, U.S. Pat. No. 3,836,979 to Kurland et al. for a "Lightweight Deployable Helical Antenna" discloses a helical antenna coiled about a longitudinally extendable and contractible supporting structure comprising a truss frame constructed of resiliently flexible strain energy beams. The antenna is collapsible to a relatively compact configuration for stowage and erects automatically, when released, under the force of the strain energy stored in the antenna beams.

U.S. Pat. No. 4,068,238 to Acker for an "Elastic Strain Energy Deployable Helical Antenna" also discloses a helical antenna having a tubular resiliently flexible antenna element fixed at one end to a support and formed into a normally extended, resiliently compressible helix. The antenna includes a plurality of flexible tension members of shorter overall length than the axial length of the helix if the helix were allowed to become fully extended. The flexible tension members are fixed at one end to the support, extend axially of the helix, and are secured to its helical turns. The antenna is compressible axially for storage and is deployable axially by stored elastic strain energy to an extended operating length at which the tension members are stressed in tension by the helix to reinforce the latter against deflection laterally of its longitudinal axis.

U.S. Pat. No. 4,780,727 to Seal et al. for a "Collapsible Bifilar Helical Antenna," discloses a bifilar helical antenna wound about a rigid mast and a plurality of support arms. The support arms are slidable along the axis of the mast to allow for expansion and contraction of the helices. The mast includes multiple sections which can be added or removed to permit adjustment of the axial length of the mast.

U.S. Pat. No. 3,059,322 to Teague for a "Method of Making a Collapsible Antenna of Wire Mesh" discloses a collapsible antenna which can be rolled and unrolled manually into, respectively, a collapsed and extended condition. The antenna, which is not a helical antenna, is constructed of wire mesh.

While these antennae may be stored in a smaller volume in their collapsed state than in their deployed configuration, none provides the flexibility and compactness of the present invention. Moreover, unlike the antenna of the present invention, the helical antennae described in the foregoing patents, among other things, are only capable of longitudinal contraction. While such antennae may be acceptable for helical antennae being deployed on Earth, they are not adapted for automatic deployment from a compactly stowed to extended position on a spacecraft in space. Typically, a spacecraft deployable structure requires a mechanical means, such as a separate spring or motor, to supply the requisite motive force to extend the antenna from its collapsed state. Any mechanical failure results in such antenna not being properly deployed. Thus, a self-deploying antenna not susceptible to such mechanical failure is desirable.

SUMMARY AND OBJECTS OF THE INVENTION

It is a general object of the present invention to provide a self-deploying, helical structure.

It is a more precise object of the present invention to provide a helical structure capable of being partially crumpled into a compact volume for storage and of self-deploying using energy stored in the crumpled helical structure.

Another primary object of the present invention is to provide a highly reliable, helical antenna that does not require any external energy to deploy it from a collapsed to a fully extended configuration.

These objects are accomplished in the present invention by a helical structure capable of being stowed in a rolled-up or other distorted configuration occupying a compact volume. The helices comprise resilient strips having one end attached to a top ring and the other end attached to a bottom ring. Intermediate rings are included throughout the length of the structure for added stability.

The resilient strips are placed around an aluminum mandrel in the desired helical configuration. The strips are attached at each of their ends to an end ring. Intermediate rings are attached around the resilient helical strips to help hold the helical strips in their desired spaced relationship. The apparatus then is heated and allowed to cool before it is removed from the mandrel. This heating and cooling process causes the helical strips to retain their shape. Conductive strips are attached to some or all of the resilient strips to form the antenna.

The entire helical structure can be rolled up or its normal configuration otherwise distorted for storage in a compact volume. Later, when released, the structure is self-deployed by the energy stored in the resilient helical strips as they resume their helical configuration. Thus, once released from its stowed position, no external means is required to deploy the structure into its extended configuration.

In a second embodiment, an antenna assembly includes several resilient helical structures, each of which has a boom segment extending axially the length thereof, with each pair of adjacent ends of the boom segments being joined together by flexible "tape" hinges. The "tape" employed has a configuration and resiliency analogous to that of a carpenter's metal measuring tape. The helical structures can be folded so that they overlie one another by deforming the tape hinges. The antenna assembly thus can be both folded and deformed for stowage in a spacecraft. Once the antenna assembly is released for deployment, the helical structures return to their original shape and the tape hinges "lock" into place so as to align the helical structures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a helical antenna of the present invention in its deployed position;

FIG. 2 is a schematic view of a portion of the helical antenna of FIG. 1 beginning to be rolled up;

FIG. 3 is a schematic view of the helical antenna of FIG. 1 in its completely rolled up position for stowage;

FIG. 4 is a schematic view of a second embodiment of the present invention shown in its deployed position and attached to a spacecraft;

FIG. 5 is a perspective view of one of the antenna elements shown in FIG. 4;

FIG. 6 is a section view taken along line 6—6 of FIG. 5;

FIG. 7 is an enlarged view of the circled portion of FIG. 6;

FIG. 8 is a perspective view of a boom design for use with the present invention;

FIG. 9 is a section view of a boom and hinge assembly taken along line 9—9 of FIG. 8;

FIG. 10 is a section view of a boom segment showing feed holes and feeds therein;

FIG. 11 is a schematic view of a boom segment showing feed holes and feeds therein;

FIG. 12 is a perspective view of a UHF antenna shown in FIG. 4;

FIG. 13 is a perspective view of an alternative embodiment of a UHF antenna shown in FIG. 4;

FIG. 14 is a section view of the antenna system of FIG. 4 stowed within a spacecraft;

FIG. 15 is a section view of the antenna system of FIG. 14 beginning to deploy;

FIG. 16 is a section view of the antenna system of FIG. 14 in the process of deploying at a time after that shown in FIG. 15; and

FIG. 17 is a section view of the antenna system of FIG. 14 deploying toward its extended configuration at a time after that shown in FIG. 16.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, an antenna **10** is shown. Antenna **10** has resilient helical strips **44***a–h*, conductive strips **54***a–d*, top ring **46**, bottom ring **48** and intermediate rings **50**.

Antenna **10** of FIG. **1** includes eight resilient helical strips **44***a–h*. Resilient helical strips **44***a–h* can be made of, for example, "S"-Glass/PEEK (Poly Ether Ether Ketone). The resiliency of this material allows antenna **10** to be rolled up or otherwise distorted from its normal configuration to fit into a compact volume and later to self-deploy. Conductive strips **54***a–d* are applied to some or all of resilient helical strips **44***a–h* by means of a pressure sensitive adhesive. Conductive strips **54***a–d* can be made of gold, copper, or other suitable conductive material as is known in the art.

A quadrifilar antenna employs four conductive strips **54***a–d*. Alternatively, as shown in FIG. **5**, a portion of the helical structure can include four conductive strips **54***a–d* wound so as to provide right hand polarization, and a second portion can include four conductive strips **52***a–d* wound so as to provide left hand polarization, thereby providing two antennae of opposite polarizations. A single polarization quadrifilar embodiment is shown in FIG. **1**. Antenna **10** includes a top ring **46** at one end to which an end of each of resilient helical strips **44***a–h* is attached. On the opposite end of antenna **10**, a bottom ring **48** is attached similarly to the opposite end of each of resilient helical strips **44***a–h*. Intermediate rings **50** are attached around resilient helical strips **44***a–h* in order to maintain the helical shape of antenna **10** when in its deployed, extended configuration. In the preferred embodiment, intermediate rings **50** are placed around each intersection of helical strips **44***a–h* as well as around the midpoint between successive intersections of helical strips **44***a–h*.

In FIG. **1**, conductive strips **54***a–d* are wound so as to overlie four helical strips **44***a–d* travelling around the mandrel in the same direction (i.e., forming either a right-handed or left-handed helix, depending upon the desired antenna polarization). Conductive strips **54***a–d* are wound spaced 90° apart. In the alternative embodiment discussed above and shown in FIG. **5**, conductive strips can be wound in both directions (i.e., some conductive strips **54***a–d* forming a right-handed helix and some conductive strips **52***a–d* forming a left-handed helix).

Antenna **10** is constructed by first placing top ring **46** and bottom ring **48** around an aluminum mandrel. Resilient helical strips **44***a–h* are wound around the mandrel and attached at their ends to top ring **46** and bottom ring **48**. In the antenna of FIGS. **1** and **5**, four resilient helical strips **44***a–d* spaced 90° apart are wound in one direction to form a right-handed helix and the other four resilient helical strips **44***e–h* spaced 90° apart are wound in the opposite direction to form a left-handed helix. Intermediate rings **50** are attached to the exterior of resilient helical strips **44***a–h* to help hold helical strips **44***a–h* in their desired relationship and to maintain a cylindrical shape. In the preferred embodiment, top ring **46**, bottom ring **48** and intermediate rings **50** are identical and are made of the same material as resilient helical strips **44***a–h*.

In the preferred embodiment, this entire structure is heated, first to 730° F. for 20 minutes under vacuum (approximately 28 inches of mercury), then at 600° F. for 30 minutes. Finally, the structure is cooled to 170° F. before releasing the vacuum. This process causes resilient helical strips **44***a–h* to retain their shape after being allowed to cool and being removed from the mandrel. Conductive strips **54***a–d* (and **52***a–d* in the FIG. **5** embodiment) are then attached to form the antenna or antennae.

When finished, antenna **10** is flexible and lightweight and can be stored in a compact volume. For example, antenna **10** can be rolled up from top ring **46** to bottom ring **48**, such that top ring **46** is in the center and bottom ring **48** is on the outer surface, i.e., in a coil configuration. FIGS. **2** and **3**, respectively, schematically show antenna **10** partially rolled and completely rolled. In addition, antenna **10** can be stowed in a partially squashed configuration to reduce its thickness, as shown in FIG. **14**.

Antenna **10** is especially useful in spacecraft applications in which payload space is at a premium. Antenna **10** requires a minimum of space because it can be rolled or otherwise deformed from its normal configuration to fit into a compact or irregular volume. When it is desired to deploy antenna **10** into its extended configuration, antenna **10** self-deploys without the use of any external force by simply releasing the energy stored in the resilient strips **44***a–h* at the time they were rolled up or otherwise deformed. Because no moving parts are required for deployment into the extended configuration, once antenna **10** is released from the rolled-up or other deformed position in which it is stowed, deployment of antenna **10** is extremely reliable.

In the embodiment shown in FIG. **1**, the helical structure serves as a helical antenna. It should be recognized, however, that the helical structure can be used in many applications other than as an antenna. For example, the helical structure can be covered with suitable material, e.g., polytetrafluoroethylene (PTFE), and used as a solar sail for positioning a satellite while in orbit. Another possible use of the helical structure is to support a tip mass and thereby provide a gravity gradient boom. By extending the boom, a satellite's orientation with respect to the Earth can be stabilized, as is known in the art.

In addition, the self-deploying, helical structure of the present invention could be used in a variety of applications on Earth where it is desirable to have a support member that can be stored compactly and that is self-deploying.

An alternative embodiment, shown in FIG. 4, uses an arrayed approach. A detailed disclosure of this arrayed approach is described in the co-pending U.S. patent application, the contents of which are hereby incorporated by reference, entitled "An Axially Arrayed Helical Antenna," Ser. No. 08/191,247, filed Feb. 4, 1994, and assigned to the same assignee as the present invention. An antenna assembly **30** comprises first and second helical array antennae, comprising, respectively, array elements **32***a,b* and **34***a,b*. Antenna assembly **30** also comprises third and fourth antennae **36***a* and **36***b*, which are mounted on either half of a helical structure **41** of the same type as shown in FIG. **5**. Third and fourth antennae **36***a* and **36***b* can be of opposite polarity by having the four conductors on the left half overlying helical strips wound with a right-handed pitch and the four conductors on the right half overlying helical strips wound with a left-handed pitch, or vice-versa.

The first antenna comprises antenna array elements **32***a,b* both of which are left-handed quadrifilar helices. The second antenna comprises antenna array elements **34***a,b* both of which are right-handed quadrifilar helices. Antenna array elements **32***a* and **34***a* are physically located on a helical structure **40** and antenna array elements **32***b* and **34***b* are physically located on a helical structure **42**.

It should be recognized that the helical structure of the present invention can be used to support antennae of more or fewer than four conductors, as desired for a particular application.

Helical structure **42** is a resilient helix comprising four "S"-Glass/PEEK resilient strips **44***a–d* and four counter-wound "S"-Glass/PEEK resilient strips **44***e–h*. As shown in FIG. **5**, each of strips **44***a–h* may actually comprise two closely spaced strips to allow for lighter weight and increased resiliency. Resilient helical strip **44***a* is parallel to strips **44***b–d* and spaced physically apart 90° from adjacent strips **44***b,d*. Each of resilient helical strips **44***b–d* has a corresponding relationship with the other strips. Resilient helical strips **44***e–h* are wound in the opposite direction of strips **44***a–d*. Each of resilient helical strips **44***e–h* is parallel to the others and spaced physically 90° apart from the two adjacent strips.

Resilient helical strips **44***a–h* are joined to end rings **46** and **48** and intermediate rings **50** using a suitable adhesive **57**, as illustrated in FIG. **7**. End rings **46** and **48** and intermediate rings **50** also are made of "S"-Glass/PEEK. Copper strips **52***a–d* and **54***a–d* are attached to the exterior of resilient strips **44***a–h*, end rings **46** and **48** and intermediate rings **50** using an adhesive **51**, e.g., thermoplastic silicone adhesive, which can be a backing on the copper strips, as shown in FIG. **7**, to form antenna array elements **32***b* and **34***b*. Copper strips **52***a–d* and **54***a–d* are preferably as wide as resilient helical strips **44***a–h*. Where resilient strips **44***a–h* are each made from two closely spaced strips, copper strips **52***a–d* and **54***a–d* preferably are wide enough to reach the outer edges of the two closely spaced strips, and the portions of copper strips **52***a–d*and **54***a–d* that are not overlying a portion of "S"-Glass/PEEK structure are removed. This removal of portions of copper strips **52***a–d* and **54***a–d* reduces the weight of the antenna system without causing any significant change in the electrical characteristics of copper strips **52***a–d* and **54***a–d*. Each of copper strips **52***a–d* and **54***a–d* includes a reflective portion **53***a–d* and **55***a–d*, respectively, which is trimmed appropriately to improve the signal pattern.

A layer **59** about 2 millimeters thick of PTFE or other suitable gathering means can cover antenna array elements **32***b* and **34***b* to provide further structural support or to allow the antenna system to be used as a solar sail, for example. A layer **61** of Kapton or other suitable Mylar or polyester film can cover the interior of antenna array elements **32***b* and **34***b* to prevent antenna array elements **32***b* and **34***b* from adhering to themselves upon deformation. Layer **59** and layer **61** can be seen most clearly in FIG. **7**. For those embodiments using spokes **58***a–h* to support a boom segment (as described below), spokes **58***a–h* are bonded to end rings **46** and **48** and therefore layer **61** does not extend to end rings **46** and **48** because layer **61** does not provide an adequate surface for bonding spokes **58***a–h*.

As most clearly seen in FIG. **6**, the interior of antenna array element **32***b* houses an "S"-Glass/PEEK hub **56** from which eight "S"-Glass/PEEK spokes **58***a–h* emanate. Spokes **58***a–h* are attached to end ring **46**, for example, in the same manner as rings **46** and **48** are bonded to helical strips **44***a–h*. A boom segment **60***a* (shown in FIG. **5**, but omitted in FIG. **6** for clarity) is supported by hub **56**. A similar hub and spoke arrangement is housed within antenna array element **34***b* at the other end of the helical structure.

As shown in FIG. **4**, a boom **60**, comprising boom segments **60***a–c*, extends axially through antenna array elements **32***a,b* and **34***a,b* and antennas **36***a,b*. Boom segments **60***a–c* include many common elements. Boom segments **60***a–c* are constructed from an aluminum beryllium (AlBe) alloy, AlBeMet, having a high "E" and thermal "K". Referring to FIG. **8**, four pop-up flaps **62** extend longitudinally along each of boom segments **60***a–c* to provide RF symmetry. Pop-up flaps **62** are "L"-shaped. The shorter portion of each pop-up flap **62** is bonded to the boom segment using a conductive, e.g., silver filled, epoxy. The longer portion of pop-up flap **62** normally is substantially perpendicular to boom segments **60***a–c* and will return to its substantially perpendicular orientation after being deformed to rest against boom **60** during stowage.

Pop-up flaps **62** are made from beryllium copper (BeCu) that is preformed to its desired shape and held at 90° F. in a steel die. Pop-up flaps **62** are then heat treated to 625° F. for one hour. A pair of pop-up flaps **62** is provided on the boom segment within each antenna array element **32***a,b* and **34***a,b*, and within each antenna **36***a,b*. For example, antenna **36***b* is provided with one pop-up flap **62** located on the top of boom segment **60***b* and another pop-up flap **62** located beneath boom segment **60***b*. Antenna element **36***a* also is provided with a pair of pop-up flaps **62** located on boom segment **60***b*. Thus, each of boom segments **60***a–c* has attached to it four pop-up flaps **62**—two pop-up flaps for each antenna element, with one pop-up flap of each pair above the boom segment and one pop-up flap of each pair below the boom segment.

Referring to FIG. **8**, boom segments **60***a–c* each include eight feed holes **64***a–h* for connecting each antenna array element **32***a,b* and **34***a,b* and each antenna **36***a,b* to appropriate electrical circuitry (not shown) housed within boom segments **60***a–c*.

Feed holes **64***a–d* house feeds **67***a–d*, as shown in FIGS. **10** and **11**, for one antenna array element, e.g., **32***a*, while feed holes **64***e–h* house feeds **67***e–h* for the other antenna array element, e.g., **34***a*. Feeds **67***a–h* are attached to connector blocks **69**. Feed holes **64***a,b,e,f* are located on top of each boom segment and feed holes **64***c,d,g,h* are located on

the bottom of each boom segment. FIGS. 10 and 11 schematically show the relationship between feed holes 64a–d and feeds 67a–d. As shown in FIGS. 12 and 13, boom segment 60c has an additional set of feed holes 64i–l to feed a UHF antenna 38.

Referring again to FIG. 8, conductive copper foil tape 65 covers boom segments 60a–c for grounding purposes. Tape 65 can be, but need not be, the same type of material used to form the conductive strips of the antenna.

Strips 66a–d made of BeCu form a "tape" hinge, with one end of each strip attached to the end of a first boom segment and the other end attached to a successive boom segment. Such tape hinges are used to join boom segments 60a and 60b and to join boom segments 60b and 60c. Strips 66a–d preferably are bolted to boom segments 60a–c through attachment blocks 68. Strips 66a–d are positioned with a pair of strips 66a,b above successive boom segments 60b and 60c and a pair of strips 66c,d below successive boom segments 60b and 60c. Each of strips 66a–d has a lenticular, i.e., slightly curved, cross-section as shown in FIG. 9. This shape is similar to the shape of a carpenter's metal measuring tape. This shape makes the tape hinges stiff when opened. Strips 66a–d can be bent 180° when antenna assembly 30 is stowed in a satellite. When antenna assembly 30 opens after deployment, the tape hinges lock into opened position and return boom segments 60a–c into an aligned configuration.

Boom segments 60a–c can house within them circuit boards 63 that are attached to attachment blocks 68 having cable connectors. Attachment blocks 68 also facilitate attachment of the "tape" hinges formed from strips 66a–d. Cable service loops 70 are provided at each hinged joint. Boom segment 60a is supported near each end by a hub 56 and spokes 58a–h. Similar hubs and spokes (not shown) support boom segments 60b and 60c. Boom segment 60a also can have, for example, a magnetometer 72 for determining the location of the satellite with respect to the Earth by measuring the Earth's magnetic field.

UHF antenna 38 of FIG. 12 is made of "S"-Glass/PEEK resilient strips 76 and conductive copper strips 78 in a manner analogous to that described above for the other antennae. UHF antenna 38 extends beyond antenna array element 32a. Resilient strips 76 of UHF antenna 38 are shaped in a manner analogous to resilient strips 44a–h of antenna array elements 32b and 34b. In the embodiment shown, conductive copper strips 78 form a right-handed quadrifilar helix about resilient strips 76. If desired, a left-handed quadrifilar helix could be formed instead. Coaxial feeds from feed holes 64i–l of boom segment 60c are soldered and bonded to the ends of the respective helical conductive copper strips 78.

UHF antenna 38 also includes an "S"-Glass/PEEK lenticular stiffener 80 bonded to the interior of UHF antenna 38. One end of lenticular stiffener 80 is attached to the end of boom segment 60c and functions as a bendable hinge. Lenticular stiffener 80 is attached to boom segment 60c, for example, by bolting. A curved spacer 81 made of PTFE facilitates this attachment by filling the space between the bottom of boom segment 60c and the top of lenticular stiffener 80. Thus, when antenna assembly 30 is stowed, the end of stiffener 80 near boom segment 60c is bent back so that stiffener 80 and antenna 38 are folded against helical structure 40. Upon being released for deployment, the resilient nature of stiffener 80 causes it to straighten out again so as to axially align stiffener 80 and boom segment 60c.

A PTFE distributed gravity gradient mass 82 is bonded to lenticular stiffener 80. Distributed gravity gradient mass 82 biases the satellite in a desired direction with respect to the Earth to facilitate attitude control of the spacecraft. Gravity gradient mass 82 is distributed along a length of stiffener 80 to be more easily supportable.

Alternatively, as shown schematically in FIG. 13, a boom segment 84 extends through and beyond UHF antenna 38. Unlike boom segments 60a–c, boom segment 84 is solid and made of a non-metallic, dielectric material such as Torlon, a polyamide-imide. As such, boom segment 84 does not require pop-up flaps. Boom segment 84 is supported by a hub and spoke arrangement (not shown) similar to those supporting boom segments 60a–c and is joined with boom segment 60c using strips 66a–d analogous to the strips connecting the other boom segments. An "S"-shaped actuator hold down bracket 86 can be integral with, or have one end bolted to, boom segment 84. Hold down bracket 86 is attached to a non-explosive actuator 112 more fully described below.

FIG. 14 depicts in cross-section antenna assembly 30 stowed within a spacecraft 114 prior to deployment. Antenna assembly 30 is folded at tape hinges 66 (illustrated schematically in FIG. 14) so that the antenna elements overlie one another. In this stowed position, UHF antenna 38, helical structures 40, 41 and 42 and their corresponding antennae are resiliently compressed to occupy a smaller thickness and thereby fit within the space between shelf 108 and solar array panel 100b. The end of boom 60 is attached to a 180° constant torque hinge 104. One suitable hinge is described in the co-pending U.S. patent application, the contents of which are hereby incorporated by reference, entitled "Shear Viscous Damped Hinge," Ser. No. 08/191, 246 filed Feb. 4, 1994, and assigned to the same assignee as the present invention. Antenna assembly 30 is disposed against a payload shelf 108. Solar array panels 100a and 100b are attached to spacecraft 114 via solar array hinges 102a and 102b. Solar array panels 100a and 100b form a top and bottom to spacecraft 114. A double lanyard non-explosive actuator (not shown) restrains solar array panels 100a and 100b during launch. Snubbers 106 provide for shock absorption during launch of the satellite.

When antenna assembly 30 is to be deployed, the double lanyard non-explosive actuator is released and solar array panels 100a and 100b pivot 90° about solar array hinges 102a and 102b. As solar array panel 100b is rotated, first phase deployment begins. Antenna assembly 30 springs out by a combination of: (1) the strain energy stored in antenna assembly 30 when it is partially flattened between solar array panel 100b and payload shelf 108; and (2) the urging of 180° constant torque hinge 104. At this point, lenticular stiffener 80 of UHF antenna 38 is held to boom segment 60a via a single lanyard non-explosive actuator 112 with a delrin spacer 110 holding lenticular stiffener 80 to non-explosive actuator 112. In the embodiment using boom segment 84 within UHF antenna 38, actuator hold down bracket 86 is attached directly to non-explosive actuator 112 and delrin spacer 110 is omitted.

Thus, as shown in FIG. 15, when solar array panel 100b releases antenna assembly 30, antenna assembly 30 begins to pivot about torque hinge 104. Antenna assembly 30 will pivot 180° about constant torque hinge 104 to the location depicted in FIG. 16. When antenna assembly 30 has pivoted 180°, phase one deployment is complete.

At this point, a single lanyard non-explosive actuator 112 is released to begin phase two deployment. Non-explosive

actuator **112** separates UHF antenna **38** from boom segment **60a**. Antenna assembly **30** begins to unfold with the various antenna elements moving in the direction of the arrows shown in FIG. **17**. Antenna assembly **30** continues to unfold until it reaches the deployed configuration shown in FIG. **4**. Tape hinges **66** and lenticular stiffener **80** snap back into an axially aligned orientation. Not only does antenna assembly **30** unfold into alignment, each helical element of antenna assembly **30** springs back to a shape having a substantially circular cross-section. This return to shape allows the various antennae of antenna assembly **30** to operate.

Whereas the present invention has been described with respect to specific embodiments thereof, it will be understood that various changes and modifications will be suggested to one skilled in the art and it is intended that the invention encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A method of making a resilient, flexible helical structure, comprising the steps of:

(a) joining at least one flexible support strip to at least one flexible conductive strip;

(b) attaching one end of the at least one joined support strip and conductive strip to a first ring;

(c) wrapping the at least one joined support strip and conductive strip around a mandrel to form at least one helical strip;

(d) attaching a second end of the at least one helical strip to a second ring to form the helical structure;

(e) treating the helical structure so that it will retain its shape and be resiliently compressible in a direction perpendicular to its longitudinal axis; and

(f) removing the helical structure from the mandrel.

2. The method of claim **1** further comprising the step of attaching at least one intermediate ring to the at least one helical strip.

3. The method of claim **1** wherein said treating of said helical structure comprises heating said helical structure while said helical structure is around said mandrel.

4. The method of claim **1** wherein said treating step further comprises treating the helical structure so that it is stowable in a first, coiled configuration with the at least one helical strip coiled about the first ring and with the second ring positioned on the outside of the coil and in which energy is stored in the at least one coiled, resilient helical strip so that the helical structure is self-deployable by the release of the energy stored in the at least one coiled, resilient helical strip into a second, extended boom configuration with the first ring and the second ring positioned at opposite ends thereof.

5. A self-deploying helical structure, comprising:

a plurality of resilient helical strips;

a top ring attached to support one end of each said helical strip; and

a bottom ring attached to support a second end of each said helical strip;

wherein the helical structure is stowable in a first, coiled configuration with said helical strips coiled about said top ring and with said bottom ring positioned on the outside of the coil and in which energy is stored in said coiled, resilient helical strips; and

wherein the helical structure is self-deployable by the release of the energy stored in said coiled, resilient helical strips into a second, extended boom configuration with said top ring and said bottom ring positioned at opposite ends thereof.

6. The self-deploying helical structure of claim **5** wherein said helical strips are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure.

7. A self-deploying helical antenna, comprising:

a plurality of resilient helical strips;

a top ring attached to support one end of each said helical strip;

a bottom ring attached to support a second end of each said helical strip; and

at least one conductive strip, each said conductive strip having substantially its entire length bonded to at least one of said resilient helical strips;

wherein the helical antenna is stowable in a first, coiled configuration with said helical strips coiled about said top ring and with said bottom ring positioned on the outside of the coil and in which energy is stored in said coiled, resilient helical strips; and

wherein the helical antenna is self-deployable by the release of the energy stored in said coiled, resilient helical strips into a second, extended boom configuration with said top ring and said bottom ring positioned at opposite ends thereof.

8. The self-deploying helical antenna of claim **7** wherein said helical strips are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical antenna.

9. A self-deploying solar sail, comprising:

a plurality of resilient helical strips;

a top ring attached to support one end of each said helical strip;

a bottom ring attached to support a second end of each said helical strip; and

gathering means for receiving solar energy, said gathering means being attached to said helical strips;

wherein the solar sail is stowable in a first, coiled configuration with said helical strips coiled about said top ring and with said bottom ring positioned on the outside of the coil and in which energy is stored in said coiled, resilient helical strips; and

wherein the solar sail is self-deployable by the release of the energy stored in said coiled, resilient helical strips into a second, extended boom configuration with said top ring and said bottom ring positioned at opposite ends thereof.

10. The self-deploying solar sail of claim **9** wherein said helical strips are resiliently compressible in a direction perpendicular to the longitudinal axis of the solar sail.

11. A method of making a resilient, flexible helical structure, comprising the steps of:

(a) joining at least one flexible support strip to at least one flexible conduct ive strip;

(b) attaching one end of the at least one joined support strip and conductive strip to a first ring;

(c) wrapping the at least one joined support strip and conductive strip around a mandrel to form at least one helical strip;

(d) attaching a second end of the at least one helical strip to a second ring to form the helical structure;

(e) treating the helical structure so that it is stowable in a first, coiled configuration with the at least one helical strip coiled about the first ring and with the second ring positioned on the outside of the coil and in which energy is stored in the at least one coiled, resilient helical strip so that the helical structure is self-

deployable by the release of the energy stored in the at least one coiled, resilient helical strip into a second, extended boom configuration with the first ring and the second ring positioned at opposite ends thereof; and

(f) removing the helical structure from the mandrel.

12. The method of claim 11 wherein said treating step further comprises treating the helical structure so that it will retain its shape and so that the at least one helical strip is resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure.

13. A compressible helical stricture, comprising:

a plurality of resilient helical strips;

a top ring attached to support one end of each said helical strip;

a bottom ring attached to support a second end of each said helical strip; and

a plurality of copper strips, each said copper strip having substantially its entire length attached to at least one of said resilient helical strips;

wherein the helical structure is stowable in a first, coiled configuration with said helical strips coiled about said top ring and with said bottom ring positioned on the outside of the coil and in which energy is stored in said coiled, resilient helical strips; and

wherein the helical structure is self-deployable by the release of the energy stored in said coiled, resilient helical strips into a second, extended boom configuration with said top ring and said bottom ring positioned at opposite ends thereof.

14. The compressible helical structure of claim 13 wherein said helical strips are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure.

15. A self-deploying helical structure, comprising:

a plurality of resilient helical strips;

a top ring attached to support one end of each said helical strip; and

a bottom ring attached to support a second end of each said helical strip;

wherein said helical strips are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure; and

wherein said top ring and said bottom ring are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure.

16. The helical structure of claim 15 further comprising a plurality of intermediate rings attached to support said helical strips between said top ring and said bottom ring, wherein said intermediate rings are resiliently compressible in a direction perpendicular to the longitudinal axis of the helical structure.

* * * * *

US006043781A

United States Patent [19]

Toh et al.

[11] **Patent Number:** **6,043,781**

[45] **Date of Patent:** **Mar. 28, 2000**

[54] **LOW INSERTION LOSS CONNECTION OF AN ANTENNA TO A MOBILE RADIO WITH RETRACTABLE SWIVELING ANTENNA FEATURE**

[75] Inventors: **Alex Toh**, San Diego, Calif.; **Charlie McCarrick**, Plymouth, Mass.; **John Ratzel**, San Diego, Calif.

[73] Assignee: **Hughes Electronics Corporation**, El Segundo, Calif.

[21] Appl. No.: **09/097,803**

[22] Filed: **Jun. 16, 1998**

[51] **Int. Cl.**[7] **H01Q 1/24**

[52] **U.S. Cl.** **343/702**; 343/906

[58] **Field of Search** 343/702, 900, 343/901, 906, 715, 858, 850; 439/578, 581; 455/90, 129, 269, 575; H01Q 1/24

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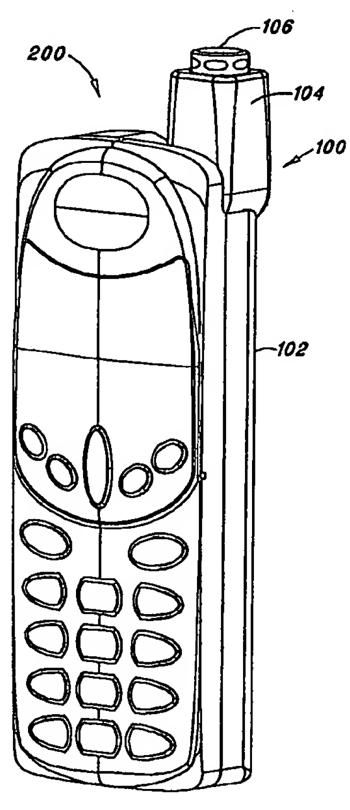
Primary Examiner—Hoanganh Le
Assistant Examiner—Tho Phan
Attorney, Agent, or Firm—Michael W. Sales; John T. Whelan

[57] **ABSTRACT**

An approach for connection of an antenna employs an antenna including at least one antenna contact; a swivel collar slidably coupleable with the antenna and including at least one collar contact; and an antenna coupler/connector insertable into the swivel collar. The approach may also be characterized as involving moving an antenna by sliding the antenna within a swivel collar, moving an antenna contact at an end of the antenna away from a swivel contact in the swivel collar; and inserting an antenna coupler/connector into the swivel collar including contacting the collar contact with a contact pad on the antenna coupler/connector. An alternative the approach may have an antenna including at least one antenna contact; a swivel collar slidably coupleable with the antenna and including at least one collar contact; a cavity enveloping the antenna when the at least one antenna contact is displaced away from the at least one collar contact, and a spring interposed between the basal end of the antenna and a basal end of the cavity for moving the antenna when the at least one antenna contact is not displaced away from the at least one collar contact.

19 Claims, 8 Drawing Sheets



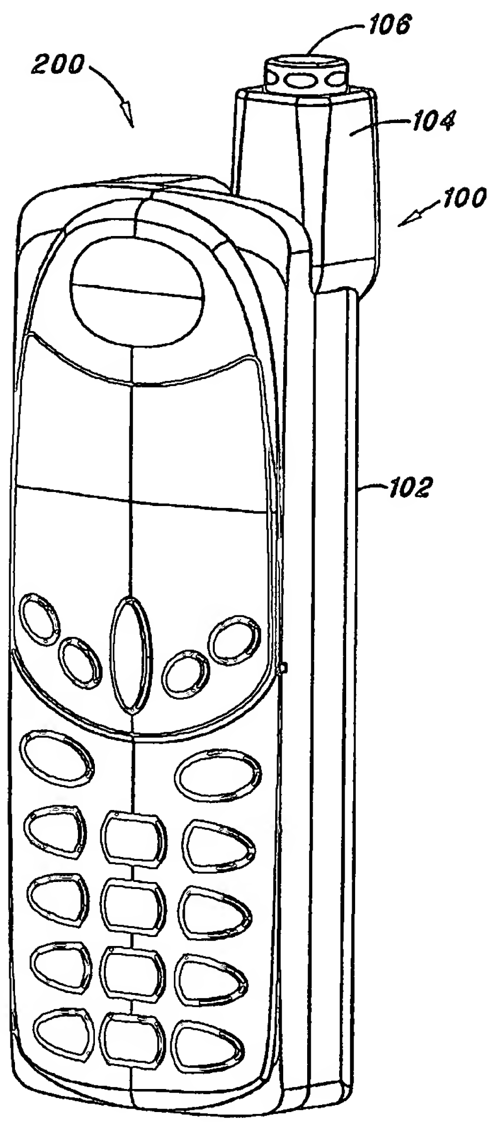


FIG. 1

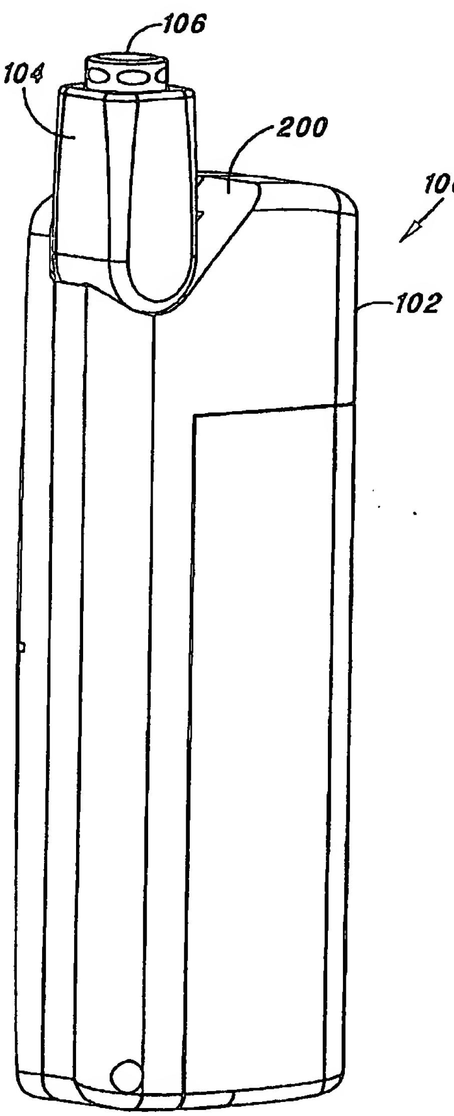


FIG. 2

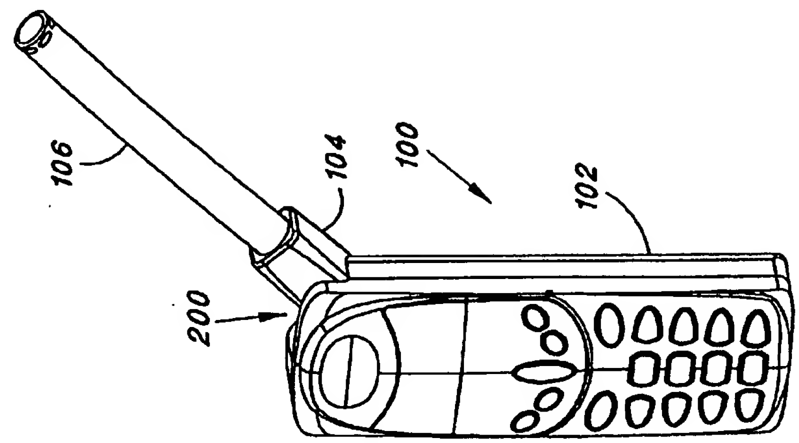


FIG. 5

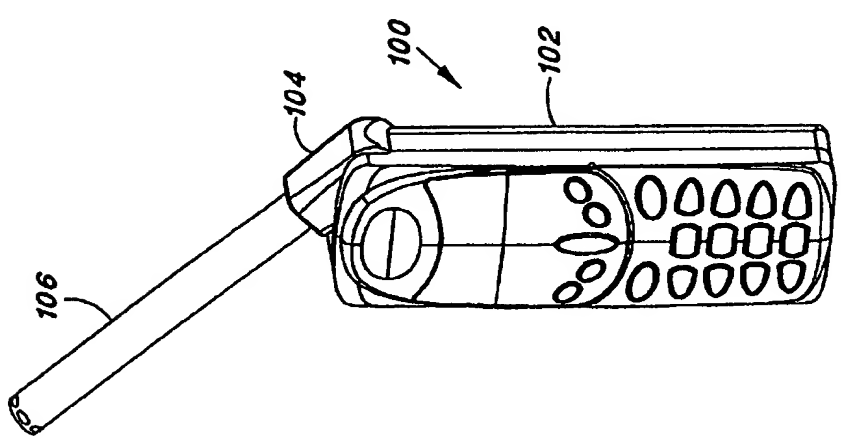


FIG. 4

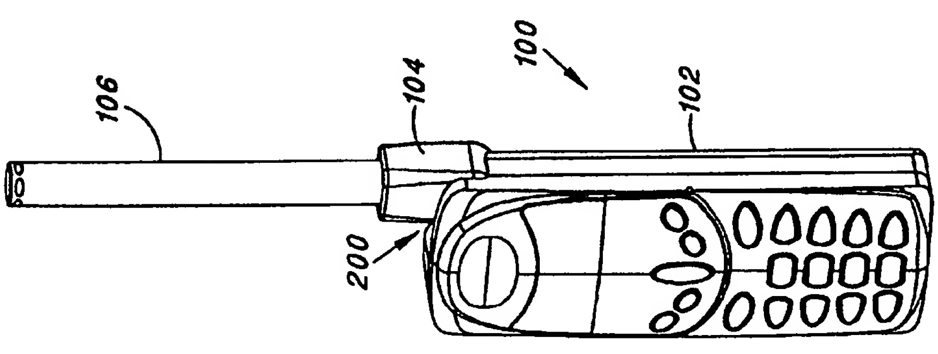
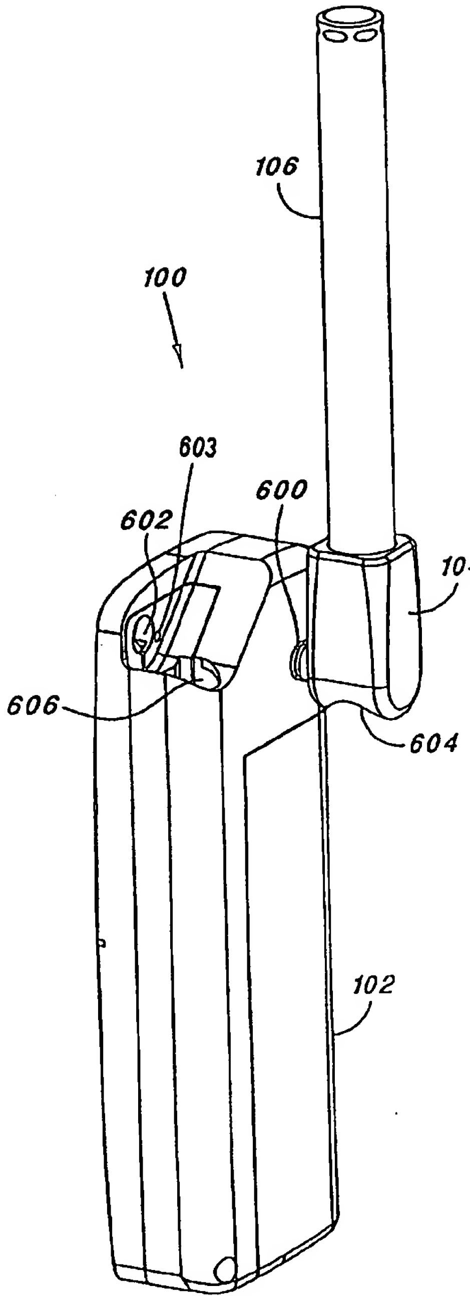


FIG. 3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102

FIG. 6

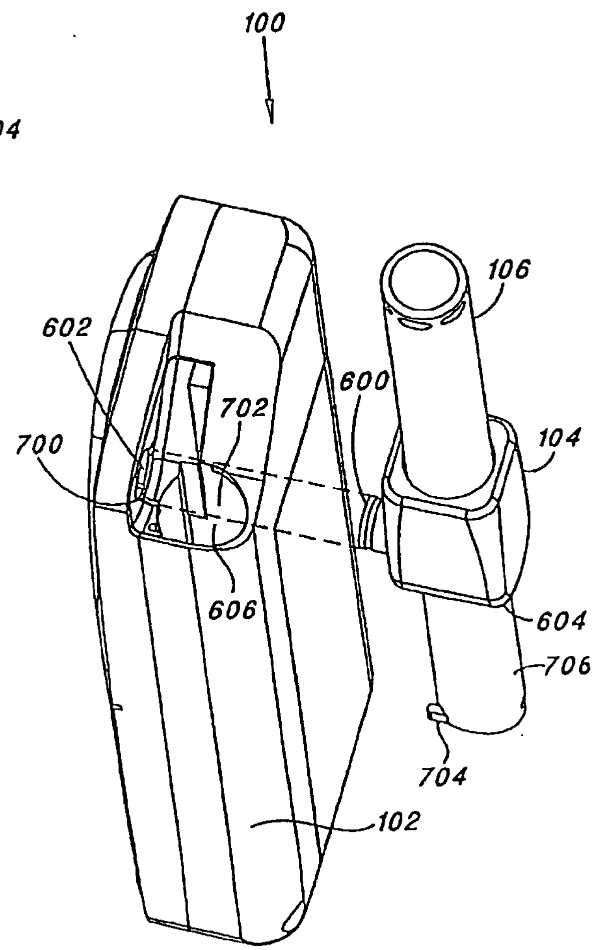
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FIG. 7

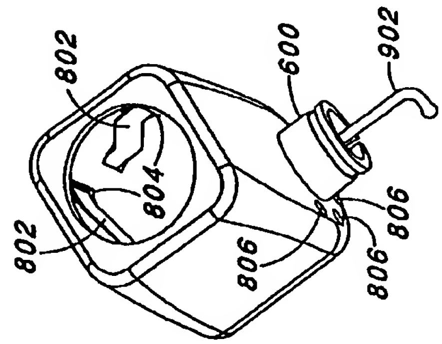

FIG. 10

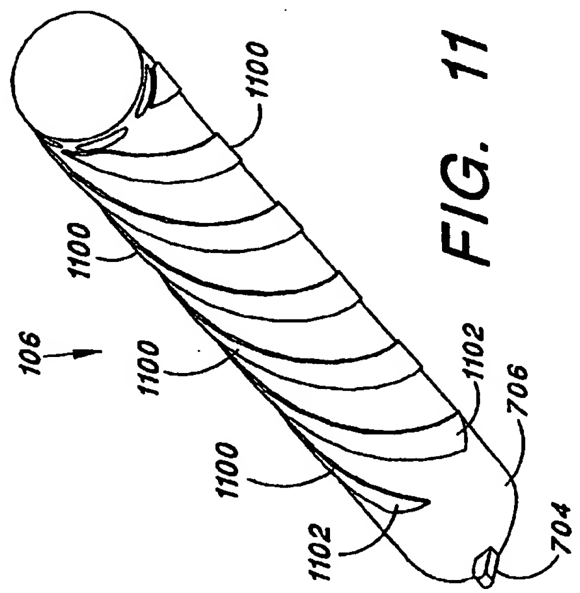

FIG. 11

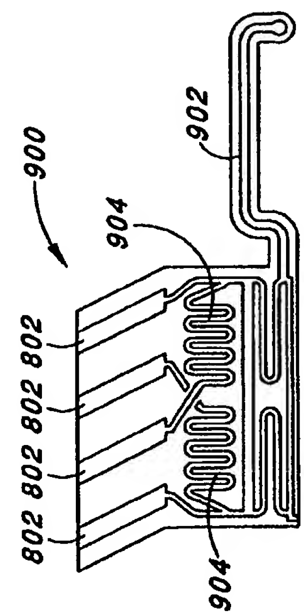

FIG. 9

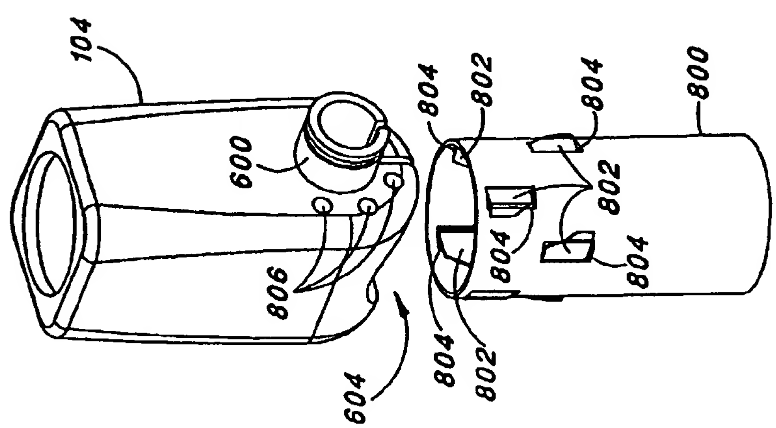

FIG. 8

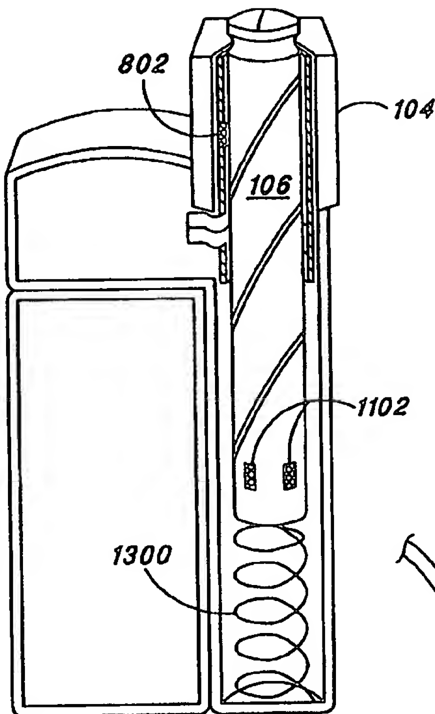

FIG. 13

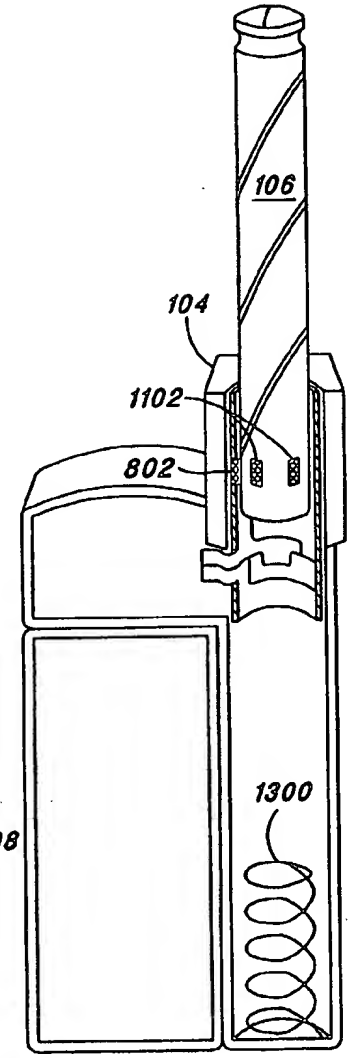

FIG. 14

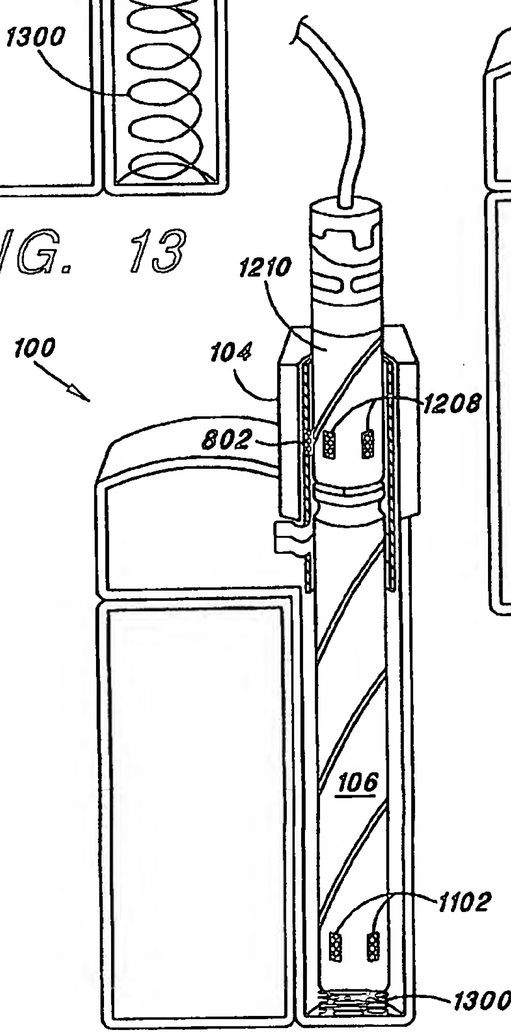

FIG. 12

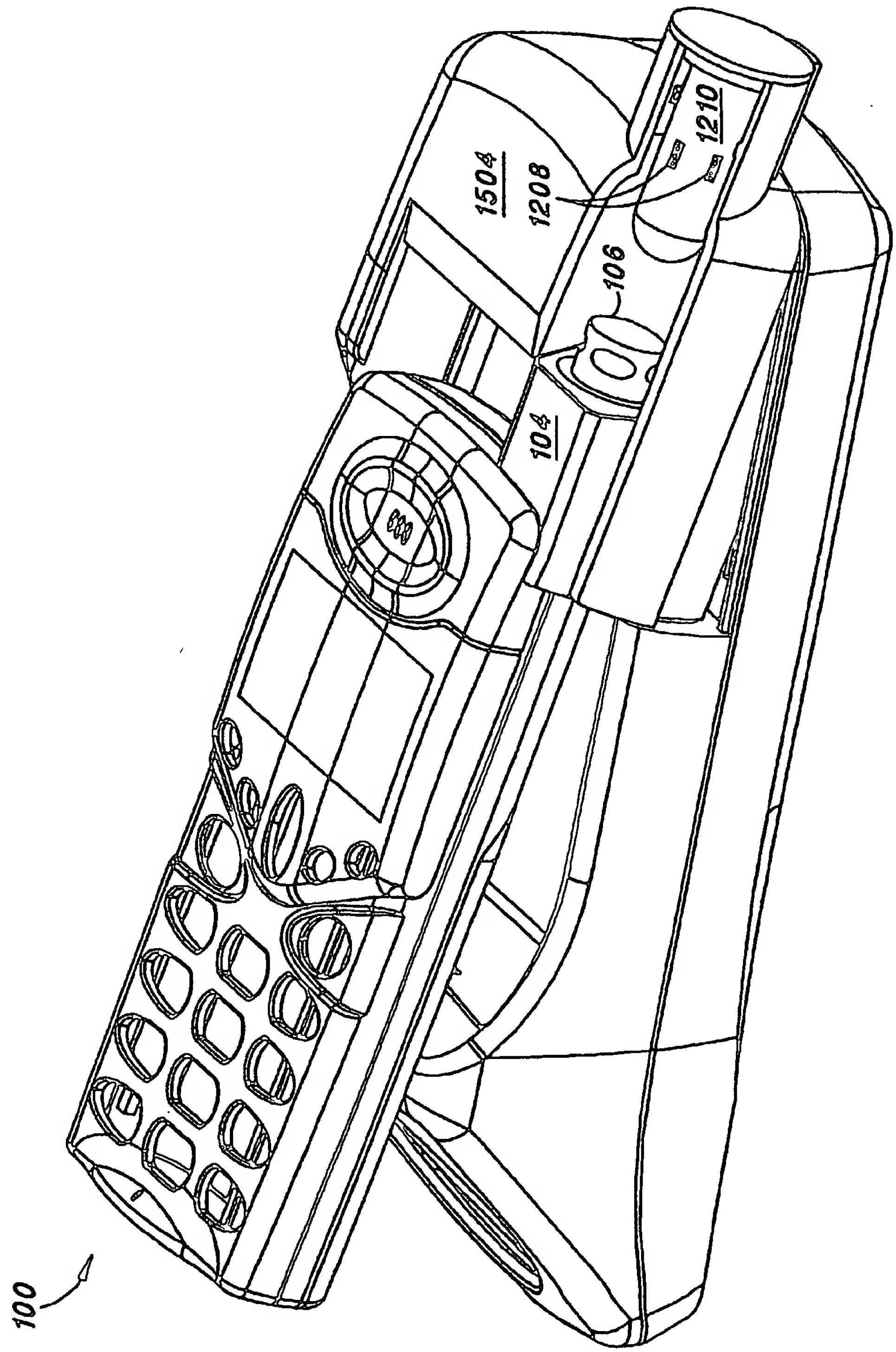

FIG. 15

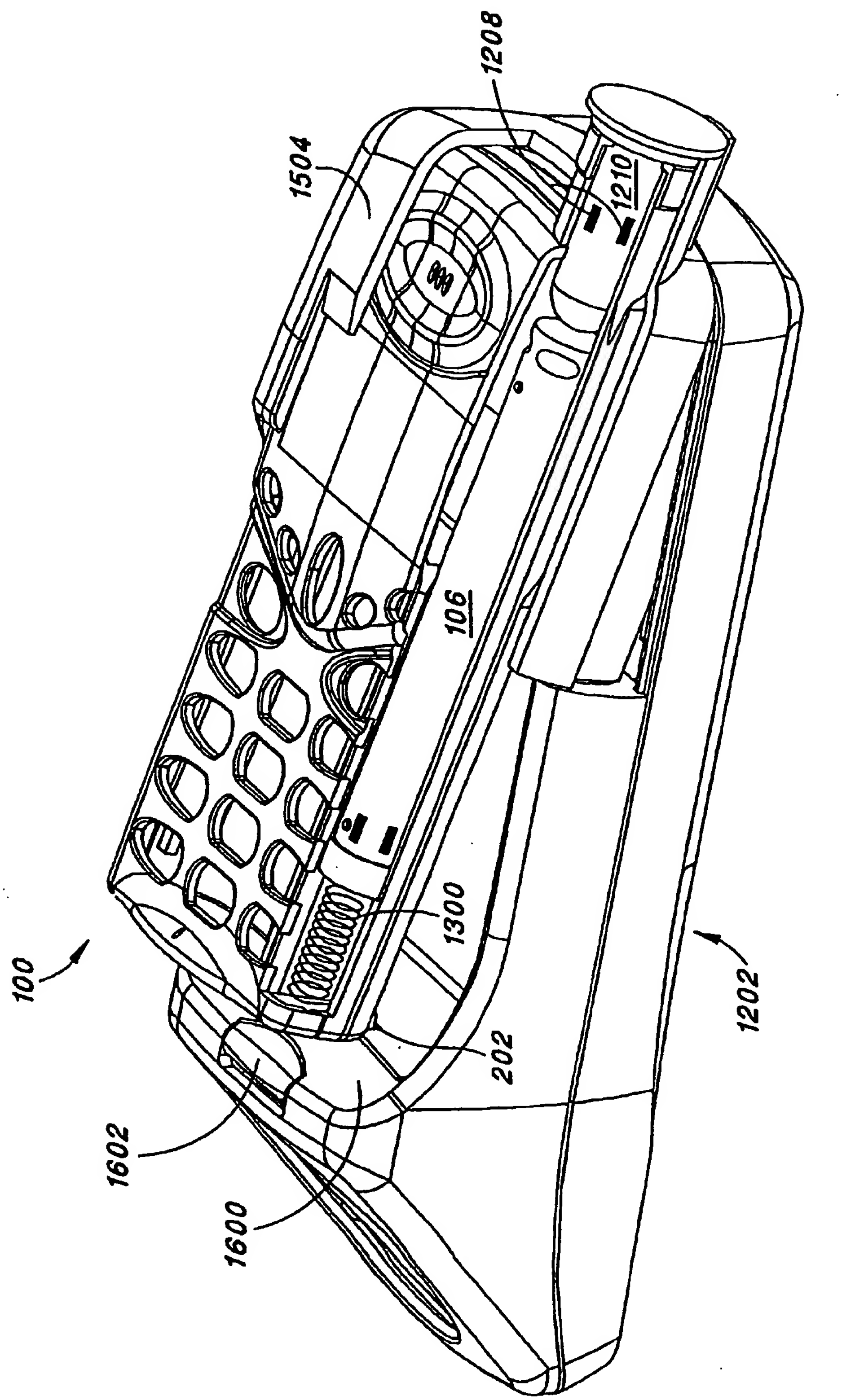

FIG. 16

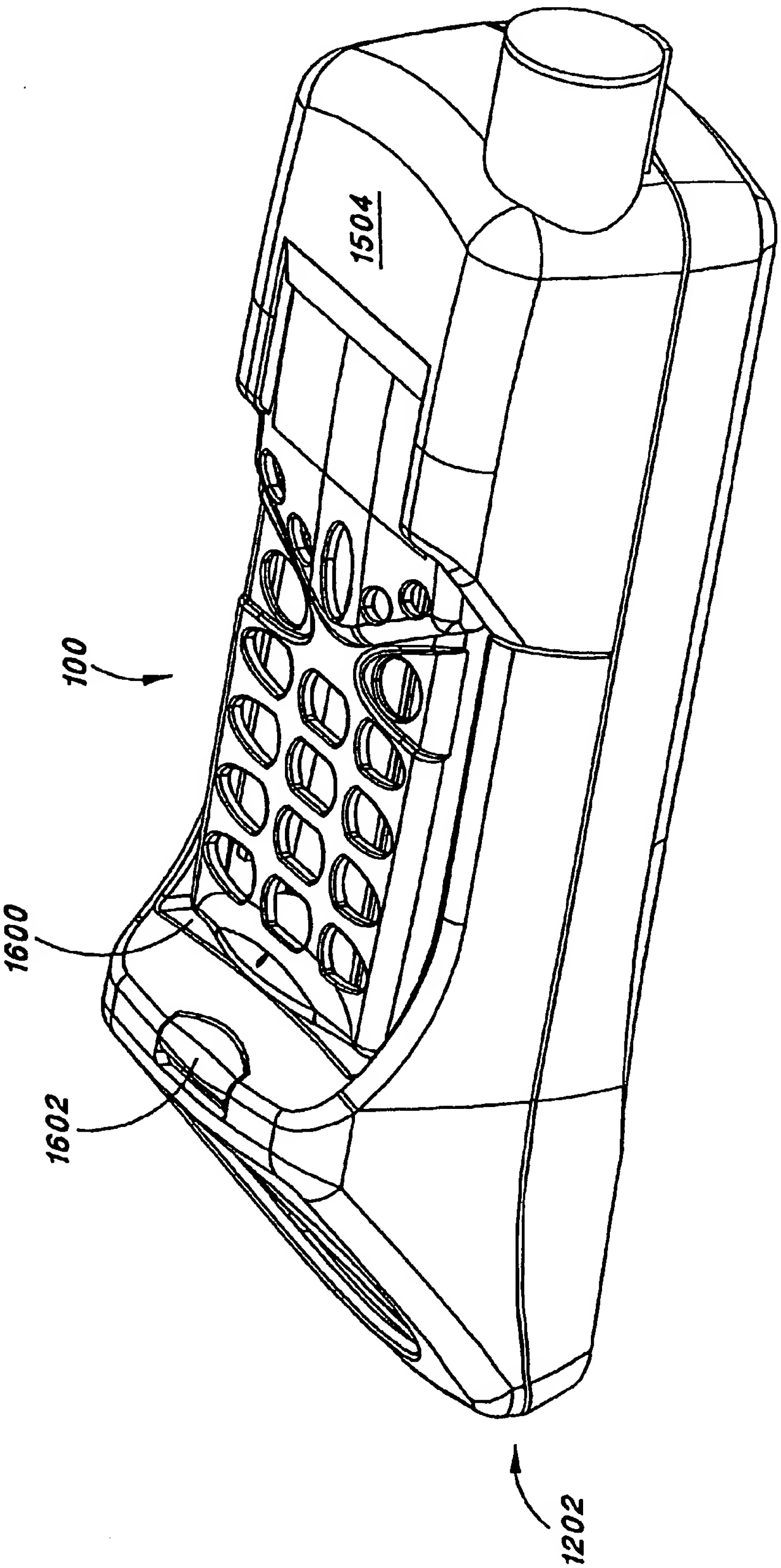

FIG. 17

LOW INSERTION LOSS CONNECTION OF AN ANTENNA TO A MOBILE RADIO WITH RETRACTABLE SWIVELING ANTENNA FEATURE

BACKGROUND OF THE INVENTION

The present invention relates to low insertion loss connection of an antenna to a mobile radio, and more particularly to low insertion loss connection of an antenna to a satellite telephone. Even more particularly, the present invention relates to low insertion loss connection of an antenna to a satellite telephone with a swivel collar that allows a retractable antenna to swivel when deployed. Even more particularly, the present invention relates to a satellite telephone with a swivel collar that has two or more fixed detente positions to allow the user to fix an angle of swivel to one of the detente positions depending on whether the user holds the telephone in a left or right hand so that the antenna is pointing approximately vertically upwards in either case. Even more particularly, the present invention relates to a satellite telephone with a swivel collar and antenna slidable within the swivel collar so that the antenna can retract into a body of the telephone for protection from the elements, and against knocks and bumps as well as to keep maintain the appearance of the telephone as neat and tidy. Even more particularly, the present invention relates to a satellite telephone with a swivel collar and antenna slidable within the swivel collar so that the antenna is in an upright position, pointing vertically upwards and more or less in a direction of a satellite, ready to receive a call even when the antenna is in a retracted position as long as the telephone is stowed upright in a shirt pocket or jacket, on a belt clip, or left standing upright on a flat surface like a desk top or table. Even more particularly, the present invention relates to a satellite telephone with a swivel collar that has an antenna matching circuit built into it to allow a relatively lesser number of connections passing through a swivel joint for better reliability than in a case where the matching circuit is separate from the antenna, and to allow the antenna to be made shorter than in another case where the matching circuit is built into the antenna.

In non-satellite transceivers, such as conventional cellular telephones, a connection to an external vehicular antenna can be made through a radio frequency connector normally located on the bottom of the telephone. In order to prevent both the phone antenna and the external vehicular antenna from radiating and/or receiving radio frequency energy at the same time, which can cause phasing and other problems, a radio frequency switch in the conventional cellular telephone switches internal connections from the telephone antenna to the external vehicular antenna connected to the radio frequency connector, when a connection is detected.

In satellite transceiver applications, such as in satellite telephones, the use of a radio frequency switch for the purpose of switching internal connections from the phone antenna to the external vehicular antenna is not desirable due to the high insertion loss of the radio frequency switch. This high insertion loss is particularly problematic in satellite telephones because of the limited loss budget due to the greater distance between the satellite telephone and an earth orbit satellite with which it communicates. In order to make up this loss on the satellite side, by building a more sophisticated satellite, extremely high costs would be involved, such as on the order of 40 million dollars.

One way in which to eliminate the radio frequency switch is to simply use a detachable connector to connect the

phone's antenna to the satellite telephone, and when use of the external vehicular antenna is desired to remove the telephone antenna and to connect vehicular antenna to the site on the satellite telephone from which the telephone antenna was removed. This approach is, however, awkward and time consuming, and therefore not highly desirable.

Another approach is to employ an inductive coupler that, when the satellite telephone is inserted into a docking adaptor in the vehicle, surrounds the telephone antenna (or a portion thereof) providing an inductive link between the external antenna and the satellite telephone. This approach, however, fails to achieve direct contact or close capacitive coupling between the vehicular external antenna and the satellite telephone, and thus also suffers from high insertion loss.

Another difficulty faced in a satellite telephone environment is the need to angle adjust or swivel the telephone antenna. This ability to angle adjust the antenna so as to aim the antenna toward the satellite with which it is communicating is needed because the telephone antenna's gain pattern is directional, and in a hand-held satellite telephone, a user is limited as to the angle at which the satellite telephone can be held in order to aim the antenna while at the same time maintaining the satellite telephone itself in a useable position near the user's ear and mouth.

As a result, all presently-available satellite telephones, and most global positioning system receivers for that matter, include a swivel joint at the attachment of antenna to the telephone or receiver. When the antenna is completely folded against the satellite telephone or global positioning system receiver's housing, it is in a storage position, and by swiveling the antenna up so as to aim it at the satellite or satellites with which it is communicating, the antenna is placed into a deployed position.

This approach however fails to address the problem that the antenna is alongside the housing of the telephone in the stowed position and not adequately protected from the elements and against knocks and bumps, as well as not in line with the appearance of a whole and integral unit. This approach also fails to address the problem that the antenna is not able to receive a call when it is in the stowed position because it is pointing in a wrong direction.

Another approach is to have a telescoping antenna, similar to antennas commonly used with portable AM/FM broadcast radio receivers, where a lower antenna element pivots relative to a housing body. This approach, however, fails to allow the antenna to slide into the housing of the radio for full retraction and protection.

Yet another approach is to have a pivot on the antenna element itself with the antenna and pivot together slidable into a channel of the radio receiver's housing body. This approach, however, adds to the length of the antenna because a matching circuit has to be placed within the antenna element above the pivot, as a connection between the matching circuit and the antenna has to be rigid for impedance matching, and therefore cannot be routed through the swivel joint.

The present invention advantageously addresses the above and other needs.

SUMMARY OF THE INVENTION

The present invention advantageously addresses the needs above as well as other needs by providing a low insertion loss connection of an antenna to a mobile radio.

In one embodiment, the invention can be characterized as a system for connection of an antenna to a mobile radio.

Such embodiment employs an antenna including at least one antenna contact at a basal end thereof; a swivel collar slidably coupleable with the antenna and including at least one collar contact alignable with the at least one antenna contact when the antenna is in an extended position. In a variation of the present embodiment, the system includes an antenna coupler/connector insertable into the swivel collar. The antenna coupler/connector includes an end for displacing the antenna contact away from the collar contact. The antenna coupler/connector includes at least one coupler pad alignable with the antenna feedpoint when the antenna contact is displaced away from the antenna feedpoint.

In another embodiment, the invention can be characterized as a method for connection of an antenna to a mobile radio. The method involves the steps of moving an antenna by rotating the antenna with a swivel collar and then sliding the antenna within the swivel collar, the sliding including moving the antenna from an extended position to a retracted position including moving an antenna contact at a basal end of the antenna away from a collar contact in the swivel collar. In a variation of the present embodiment, the system includes inserting an antenna coupler/connector into the swivel collar including moving the antenna from the retracted position to a depressed position, and further including contacting or capacitively coupling the collar contact in the swivel collar with a contact pad on the antenna coupler/connector.

In an even further embodiment, the invention can be characterized as a system for connection of an antenna to a mobile radio. The system of this embodiment has an antenna including at least one antenna contact at a basal end; a swivel collar slidably coupleable with the antenna and including at least one collar contact alignable with the at least one antenna contact when the antenna is in an extended position; a cavity enveloping the antenna when the at least one antenna contact is displaced away from the at least one collar contact; and a spring interposed between the basal end of the antenna and a basal end of the cavity for moving the antenna from a depressed position into a retracted position when the at least one antenna contact is not displaced away from the at least one collar contact.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects, features and advantages of the present invention will be more apparent from the following more particular description thereof, presented in conjunction with the following drawings wherein:

FIG. 1 is a front perspective view of a satellite telephone having a retractable antenna with a swiveling feature;

FIG. 2 is a back and side perspective view of the satellite telephone of FIG. 1;

FIG. 3 is a front perspective view of the satellite telephone of FIG. 1 with the antenna fully extended;

FIG. 4 is a perspective view of a satellite telephone in FIG. 1 with the antenna fully extended and swiveled to the left (as oriented in FIG. 4);

FIG. 5 is a perspective view of the satellite telephone of FIG. 1 with the antenna fully extended and swiveled to the right (as oriented in FIG. 4);

FIG. 6 is a side assembly view of the satellite telephone in FIG. 1 showing a swivel collar as it is assembled into the satellite telephone;

FIG. 7 is an assembly top view of the satellite telephone of FIG. 1 showing the swivel collar as it is assembled into the satellite telephone;

FIG. 8 is a side assembly view of the swivel collar of FIGS. 6 and 7 showing insertion of a sleeve into the swivel collar and placement of a contact strip (and matching circuit) in the sleeve;

FIG. 9 is a front view of a feed flex circuit including the contact strips of FIG. 8 in a flattened state, showing a matching circuit, and showing a connection lead for connecting to electronics within the satellite telephone of FIG. 1;

FIG. 10 is a top perspective view of the swivel collar showing interior placement of the contact strip in the sleeve, and a swivel pin through which the connection lead on the contact strip passes to connect to the electronics within the satellite telephone;

FIG. 11 is a perspective view of the antenna having been removed from the swivel collar so as to show quadrifilar antenna elements having exposed ends that make contact with the contact strip within the swivel collar;

FIG. 12 is a cross-sectional view of the satellite telephone of FIG. 15, with an antenna coupler/connector inserted therein so as to move a satellite telephone antenna into a depressed position, such as would be the case when the satellite telephone is inserted into the docking adaptor;

FIG. 13 is a cross-sectional view of the satellite telephone of FIG. 1, with an antenna coupler/connector removed and the satellite telephone antenna pushed upwardly by a spring into a retracted position;

FIG. 14 is a cross-sectional view of the satellite telephone of FIG. 1 wherein the satellite telephone antenna is in an extended portion;

FIG. 15 is a perspective view, partially in section, of the satellite telephone of FIG. 1 as it is inserted into a docking adaptor;

FIG. 16 is a perspective view, partially in section, of the satellite telephone of FIG. 1 fully inserted into a swivel pocket of the docking adaptor; and

FIG. 17 is a perspective view of the satellite telephone of FIG. 1 fully inserted into the docking adaptor.

Corresponding reference characters indicate corresponding components throughout the several views of the drawings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description of the presently contemplated best mode of practicing the invention is not to be taken in a limiting sense, but is made merely for the purpose of describing the general principles of the invention. The scope of the invention should be determined with reference to the claims.

Referring to FIG. 1, a front perspective view is shown of a satellite telephone **100** having a low insertion loss retractable antenna **106** with a swiveling feature. Shown is a satellite telephone housing body **102**, a swivel collar **104** and the antenna **106** in a retracted position.

Referring to FIG. 2, a back and side perspective view is shown of the satellite telephone **100**. Shown is the satellite telephone housing body **102**, the swivel collar **104**, and the antenna **106** in the retracted position. As can be seen, an angular notch **200** adjacent to the swivel collar **104** in the satellite telephone housing body **102** provides clearance for the swivel collar **104** to swivel toward the satellite telephone housing body **102**, as well as away from the satellite telephone housing body **102**.

Referring to FIG. 3, a front perspective view is shown of the satellite telephone **100**. Shown are the satellite telephone

housing body 102, the swivel collar 104, the antenna 106 in an extended position, such as would be the case while the satellite telephone is in use, and the angular notch 200. As shown, the swivel collar 104 and antenna 106 are in a vertical orientation, which would generally only be used for, and, in accordance with the present embodiment, must be used for, extending or retracting the antenna 106.

Referring to FIG. 4, a perspective view is shown of the satellite telephone 100 with the antenna 106 fully extended and swiveled to the left. Shown are the satellite telephone housing body 102, the swivel collar 104 and the antenna 106. The swivel collar 104 is rotated to the left, i.e., counter-clockwise as oriented in FIG. 4, so as to position the antenna 106 such that it will be in an approximately vertical orientation when the satellite telephone 100 is held proximate to a user's right ear and mouth in the user's right hand.

Referring to FIG. 5, a perspective view is shown of the satellite telephone 100 with the antenna 106 fully extended and swiveled to the right. Shown are the satellite telephone housing body 102, the swivel collar 104, and the antenna 106 in an extended position and rotated to the right or clockwise as oriented in FIG. 5, so as to position the antenna 106 such that it will be in an approximately vertical orientation with the satellite telephone 100 is held proximate to a user's left ear and mouth in the user's left hand.

Referring to FIG. 6, a side assembly view is shown of the satellite telephone 100 with the swivel collar 104 shown as it is assembled into the satellite telephone. Shown are the satellite telephone housing body 102, the swivel collar 104 and the antenna 106 in an extended position. The swivel collar 104 depicted as it is assembled to the satellite telephone housing body 102 in an assembly view. A swivel pin 600 on the swivel collar 104 is shown as is a swivel hole 602 in the satellite telephone housing body 102.

In practice, the swivel pin 600 on the swivel collar 104 is inserted into the swivel hole 612 in the satellite telephone housing body 102 and a metal retainer (not shown) is secured onto the swivel pin 600 within the satellite telephone housing body 102 so as to secure the swivel collar 104 to the satellite telephone housing body 102 while at the same time allowing the swivel collar 104 to rotate about an axis coaxial with the swivel pin 600. An opening 604 in a bottom of the swivel collar permits the antenna 106 to be pushed through the swivel collar 104 down into another hole 606 in the satellite telephone housing body 102 when it is in a depressed position. Note that alignment of this hole 606 in the swivel collar 104 with the hole 606 in the satellite telephone housing body 102 is achieved when the antenna 106 and swivel collar 104 are in an upright or vertical position, such as depicted in FIG. 3. This alignment is required before the antenna can be depressed into the satellite telephone housing body 102 in accordance with the present embodiment.

Referring to FIG. 7, a top assembly view is shown depicting insertion of the swivel pin 600 into the swivel hole 602 in the satellite telephone housing body 102. Shown are the satellite telephone housing body 102, the swivel collar 104, and the swivel pin 600, a key guide 700 along a cylindrical channel 702 in the satellite telephone housing body 702 and a key 704 on a base 706 of the antenna 106. The swivel collar 104 is shown in an assembly view relative to the satellite telephone housing body 102 with dashed lines indicating the positioning of the swivel pin 600 in the hole 602 in the satellite telephone housing body 102. The antenna 106 is shown in a partially depressed state for illustration purposes, so as to depict the antenna 106 protruding through the hole 604 in the bottom of the swivel collar and further to show the key 704 at the base 706 of the antenna. The key 704, together with the key guide 700 in the cylindrical channel 702 of the satellite telephone housing body 102, prevent rotation of the antenna 106 about its major axis so as to assure alignment of contacts (not shown) on the antenna with contacts (not shown) within the swivel collar 104.

The channel 702 in the satellite telephone housing terminates at the hole 606, described above in reference to FIG. 6.

Referring to FIG. 8, as assembly view is shown of the swivel collar 104 of FIGS. 6 and 7 showing insertion of a sleeve 800 into the swivel collar 104 and placement of a contact strip 802 into the sleeve 800. Shown are the swivel collar 104 and the swivel pin 600 with the sleeve 800 shown in an assembly view relative to the swivel collar 104 so as to illustrate both insertion of the sleeve into the hole 604 of the base of the swivel collar 104 and insertion of the contact strips 802 into four pairs of locating slots 804 in the sleeve 800. The contact strips 802 connect four quadrifilar antenna elements (not shown) on the antenna 106 (FIG. 1) to the contact strips 802 on a feedflex circuit. The contact strips 802 are four in number, and have a middle span exposed inside the sleeve 800. This middle span, having been secured in the locating slots 804, forms a leaf spring contact providing an inward spring force that assumes good contact with the quadrifilar elements (not shown) of the antenna 106 (FIG. 1). Thus, the middle spans of the respective contact strips 802 are exposed inside the sleeve 800 and will, in practice, contact the quadrifilar elements on the antenna 106 when the antenna is in an extended position. Also shown in FIG. 8 are a series of detents 806 on the swivel collar 104 that correspond with a pin 603, FIG. 6, on the satellite telephone housing body 102 so as to selectively hold the swivel collar 104 in particular rotational orientations while the antenna 106 is in the extended position. The detents 806 also help to align the antenna 106 and swivel collar 104 in an upright or vertical position (such as in FIG. 3) which is required for insertion of the antenna into the swivel collar 104 and into the channel 702 in the satellite telephone housing body 102.

Referring to FIG. 9, a front view is shown of the feedflex circuit 900 including the contact strips 802 in a flattened state and is also of a connection lead 902 for correcting to electronics within the satellite telephone housing body 102. Shown is the flex circuit 900, prior to being rolled into a cylinder and inserted into the sleeve 800 (FIG. 8).

On the feedflex circuit 900 are the four contact strips 802 that are inserted into the alignment slots 804 in the sleeve 800. Also shown are matching circuits 904 feeding the four contact strips 802. And, also shown is the connection lead 902 through which the feedflex circuit 900 is connected to the electronic circuitry within the satellite telephone housing body 102 (FIG. 1). As an alternative to the connection lead 902, a coaxial cable connection can be used to correct the feedflex circuit 900 to the electronics within the housing body 102 (FIG. 1).

Referring to FIG. 10, a top perspective view is shown of interim placement of the contact strips 802 within the sleeve 800, and the swivel pin 600 with the connection lead 902 on the feedflex circuit 900 passing therethrough. Shown are the swivel collar 104, the sleeve 800, the middle spans of contact strips 802 on the feedflex circuit 900, and the swivel pin 600. Also shown are the connection lead 902, the locating slots 804, the detents 806 for locking the swivel

collar **104** into different rotational positions in order to assist users in setting the antenna **106** to specific usage angles. As shown, the swivel pin **600** is hollow, allowing the connection lead **902** from the feedflex circuit **900** to pass through a center of the swivel pin to electronics within the satellite telephone housing body **102** (FIG. **1**). Four leaf springs are created by the middle spans of the four contact strips **802** of the feedflex circuit **900** as they pass through the locating slots **804** in the sleeve **800** so as to facilitate contact between the contact strips **802** and the quadrifilar elements on the antenna **106**.

Referring next to FIG. **11**, a perspective view is shown of the antenna **106** having been removed from the swivel collar **104** so as to show the quadrifilar elements **1100** that contact the contact strips **802**. Shown is the antenna with the four quadrifilar elements **1100** in a helical pattern around the antenna **106**. Short lengths **1102** of the quadrifilar elements **1100** near the base **706** of the antenna **106** are exposed so as to allow contact between the middle spans of the contact strips **802** and the exposed short lengths **1102** of the quadrifilar elements **1100**. Also shown in FIG. **11** is the key **704** used to prevent rotation of the antenna **106** about its major axis when the antenna **106** is retracted into and extended from the channel **606** in the satellite telephone housing body **102**. The key **704** also serves to prevent the antenna **106** from sliding completely out of the satellite telephone housing and swivel collar **104** when the antenna is extended from the satellite telephone housing body **102**.

Referring next to FIG. **12**, a cross-sectional view is shown of the satellite telephone **100**, with an antenna coupler/connector **1210** inserted therein so as to move the satellite telephone antenna **106** into a depressed position, such as would be the case when the satellite telephone **100** is inserted into a docking adaptor **1202** (FIG. **15**). Shown are the antenna coupler/connector **1210**, the antenna **106**, the swivel collar **104** (which may alternatively be a fixed antenna collar such as is described in U.S. Pat. No. 5,901,367, incorporated herein by reference.) the contact pads **1208**, and a spring **1300**.

As can be seen, the antenna coupler/connector **1210** displaces the antenna **106** downwardly, thereby depressing the spring **1300**, so as to move the satellite telephone antenna **106** away from the swivel collar **104**. In moving the satellite telephone antenna **106** away from the swivel collar **104**, the satellite telephone antenna **106** is also moved away from the contact strips **802**, which, upon insertion of the antenna coupler/connector **1210**, are connected to the contact pads **1208** on the antenna coupler/connector **1210** by means of a direct contact or capacitive coupling, thereby providing a connection between the satellite telephone **100** and an external vehicular antenna (not shown). In this position the satellite telephone antenna **106** is disabled, and the external vehicular antenna (not shown) is ready for use such as when the satellite telephone **100** is used in a vehicular, docked mode. The external vehicular antenna **5**is coupled to the antenna coupler/connector **1210** via a coaxial cable **1502**.

Referring next to FIG. **13**, a cross-sectional view is shown of the satellite telephone **100**, with the antenna coupler/connector (not shown) removed and the satellite telephone antenna **106** pushed upwardly by the spring **1300** into a retracted position. Shown are the satellite telephone antenna **106**, the swivel collar **104**, the contact strips **802** and the spring **1300**. In the position shown, i.e., the retracted position, an end of the satellite telephone antenna **106** is reachable by a user of the satellite telephone **100**, such that the satellite telephone antenna **106** can be extended from the satellite telephone **100**. However, in the retracted position, the satellite telephone antenna **106** remains out of the way of the user, and is protected from potential damage during handling of the satellite telephone **100**.

Referring next to FIG. **14**, a cross-sectional view is shown of the satellite telephone **100** when the satellite telephone antenna **106** is in an extended position. Shown are the antenna **106**, the swivel collar **104**, the contact strips **802**, and the spring **1300**. Also shown are the exposed short lengths **1102** on the satellite telephone antenna **106**. In the extended position, which is achieved by the user pulling the end of the satellite telephone antenna **106** from the retracted position into the extended position by grasping the end of the satellite telephone antenna **106** while the satellite telephone antenna is in the retracted position and extending the satellite telephone antenna **106**, the exposed short lengths **1102** at the base **706** of the satellite telephone antenna **106** contact or become capacitively coupled with the connection strips **802**, thereby coupling the satellite telephone antenna **106** to the satellite telephone **100**. In this position, the satellite telephone antenna **106** is ready for use, such as when the satellite telephone **100** is used in a mobile, hand-held mode.

In particular, and as illustrated in FIGS. **12** through **14**, it should be noted that the exposed short lengths **1102** are moved a significant distance away from the connection strips **802** when the satellite telephone antenna **106** is in the depressed position (FIG. **12**) and the antenna coupler/connecter **1210** is inserted into the satellite telephone **100**. This distance can be important in order to prevent capacitive or inductive coupling between the connection strips **802** and the exposed short lengths **1102** during operation in docked mode, which would result in high insertion losses. When the satellite telephone antenna **106** is in the extended position, however, the exposed short lengths **1102** are brought into contact with or into extremely close proximity with the connection strips **802** so as to couple the satellite telephone antenna **106** to the satellite telephone **100** with very little insertion loss.

Referring first to FIG. **15**, a perspective view is shown, partially in section, of a satellite telephone **100** as it is inserted into a docking adaptor **1502**. Shown are a swivel pocket **1504**, the swivel collar **104**, contact pads **1208**, an antenna coupler/connector **1210** and the satellite telephone antenna **106**.

The antenna coupler/connector **1210** engages as the satellite-telephone **100** is docked into the docking adaptor **1502**. The swivel pocket **1504** guides the satellite telephone **100** into the docking adaptor **1202** and lines up the swivel collar **104** with the antenna coupler/connector **1210** for blind insertion. The contact pads **1208** contact or become capacitively coupled with the connection strips **802** on the inside wall of the swivel collar **104** as the antenna **106** is inserted into the swivel collar **104** The antenna coupler/connector **1210** pushes the satellite telephone antenna **106** into the satellite telephone **100** as the satellite telephone **100** is inserted into the swivel pocket **1504**.

Referring next to FIG. **16**, a perspective view is shown, partially in section, of the satellite telephone **100** fully inserted into the swivel pocket **1504**. Shown are the satellite telephone antenna **106**, the swivel pocket **1504**, the contact pads **1208**, the antenna coupler/connector **1210** and the satellite telephone **100**. Also shown is the spring **1300** within the satellite telephone **100** that normally holds the satellite telephone antenna **106** in a position at least partially protruding from the satellite telephone **100**. The satellite telephone antenna **106** is pushed into the satellite telephone **100**

by the antenna coupler/connector **1210**, thus depressing the spring **1300**, so as to allow the antenna coupler/connector **1210** to connect the connection strips **802** in the swivel collar **104** to the contact pads **1208**. Thus, the pads **1208** inside the swivel collar **104** connect to the satellite telephone antenna **106** when the satellite telephone antenna **106** is deployed, i.e., extended, but connect to the contact pads **1208** of the antenna coupler/connector **1210** when the antenna coupler/connector **1210** is inserted into the swivel collar **104**.

Referring next to FIG. **17**, a perspective view is shown of the satellite telephone **100** fully inserted into the docking adaptor **1502**. The satellite telephone **100** and the swivel pocket **1504** are pivoted down so as to lock the satellite telephone **100** into place within the docking adaptor **1502**. A latch (see **1602** in FIG. **16**) locks the satellite telephone **100** in a down position, and contact points (not shown) on the bottom of the satellite telephone **100** mate up with battery charging and data connector connections (not shown) on a back wall **1600** of the docking adaptor **1502** when the satellite telephone **100** is pushed down. A release button **1702** is provided to release the satellite telephone **100**, which is, upon release, lifted out of the docking adaptor **1502** by the swivel pocket **1504**.

While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention set forth in the claims.

What is claimed is:

1. A system for connection of an antenna to a mobile radio comprising:

the antenna including at least one antenna contact at a basal end thereof;

a swivel collar slidably coupleable with the antenna and including at least one swivel collar contact alignable with the at least one antenna contact and electrically coupled to the mobile radio when the antenna is in an extended position, the swivel collar being rotatable in at least one direction when the antenna is in the extended position;

an alignment structure coupled to the antenna for maintaining rotational alignment of the antenna about its major axis to ensure electrical coupleability of the antenna to the mobile radio; and

an antenna coupler/connector insertable into said swivel collar, the antenna coupler/connector including an end for displacing the at least one antenna contact away from the at least one swivel collar contact, the antenna coupler/connector including at least one contact pad alignable with the at least one swivel collar contact when the at least one antenna contact is displaced away from the at least one swivel collar contact.

2. The system of claim **1** further comprising:

a cavity enveloping said antenna when said at least one antenna contact is displaced away from said at least one swivel collar contact.

3. The system of claim **1** further comprising:

a spring interposed between said basal end of said antenna and a basal end of said cavity for moving said antenna from a depressed position into a retracted position when said at least one antenna contact is not displaced away from said at least one swivel collar contact by the antenna coupler/connector.

4. The system of claim **1** further comprising:

a satellite transceiver coupled to said at least one swivel collar contact of said swivel collar.

5. The system of claim **4** further comprising:

a docking adaptor, the docking adaptor including an antenna coupler/connector.

6. A system of connection of an antenna to a mobile radio comprising:

the antenna including at least one antenna contact at a basal end thereof and an alignment structure for maintaining rotational alignment of the antenna about its major axis to ensure electrical coupleability of the antenna to the mobile radio;

a swivel collar slideably coupleable with the antenna and including at least one swivel collar contact alignable with the at least one antenna contact when the antenna is in an extended position, the swivel collar being rotatable about an axis substantially normal to a direction in which the antenna is slidable;

a cavity enveloping the antenna when the at least one antenna contact is displaced away from the at least one swivel collar contact; and

a spring interposed between the basal end of the antenna and a basal end of the cavity for moving the antenna into a retracted position when the at least one antenna contact is not displaced away from the at least one swivel collar contact.

7. The system of claim **6** further comprising:

a satellite transceiver coupled to said at least one swivel collar contact of said swivel collar.

8. A system for connection of an antenna to a mobile radio comprising:

a housing;

a swivel collar coupled to the housing and swivelable relative to the housing for swiveling the antenna when in an extended position;

an opening in the swivel collar alignable with a cavity in the housing for retraction of the antenna through the opening into the housing;

a first locking structure on said swivel collar; and

a second locking structure on said housing, wherein said first and second locking structures cooperate to fix an angle of rotation of the swivel collar relative to the housing.

9. The system of claim **8** further comprising:

an antenna matching circuit in said swivel collar.

10. A system for connection of an antenna to a mobile radio comprising:

a housing;

the antenna including at least one antenna contact at a basal end thereof;

a swivel collar slidably coupleable with the antenna and including at least one swivel collar contact alignable with the at least one antenna contact when the antenna is in an extended position, the swivel collar being rotatable in at least one direction when the antenna is in the extended position;

a first locking structure on said swivel collar; and

a second locking structure on said horsing, wherein said first locking structure and said second locking structure cooperate to fix an angle of rotation of the swivel collar relative to the housing.

11. The system of claim **10** further comprising:

a cavity enveloping said antenna when said at least one antenna contact is displaced away from said at least one swivel collar contact.

12. The system of claim 10 further comprising:

an antenna coupler/connector insertable into said swivel collar, the antenna coupler/connector including an end for displacing the at least one antenna contact away from the at least one swivel collar contact, the antenna coupler/connector including at least one contact pad alignable with the at least one swivel collar contact when the at least one antenna contact is displaced away from the at least one swivel collar contact.

13. The system of claim 10 further comprising:

a docking adaptor, the docking adaptor including an antenna coupler/connector.

14. A method of operation of an antenna in a mobile radio comprising:

moving the antenna by rotating the antenna with a swivel collar and then sliding the antenna within the swivel collar, the sliding including moving the antenna from an extended position to a retracted position including moving an antenna contact at a basal end of the antenna away from a swivel collar contact in the swivel collar; and

fixing an angle of rotation of the swivel collar relative to a housing by fixedly coupling a first locking structure on said swivel collar to a second locking structure on said housing.

15. The method of operation of claim 14 wherein said moving of said antenna by sliding said antenna within said swivel collar includes moving said antenna into a cavity.

16. The method of operation of claim 14 further comprising the steps of:

moving said antenna from a depressed position to said retracted position using a spring, including decoupling said swivel contact in said swivel collar from a contact pad on an antenna coupler/connector;

moving said antenna from said retracted position to said extended position, including connecting said swivel collar contact in said swivel collar to said antenna contact at said basal end of the antenna; and

rotating said antenna with said swivel collar.

17. The method of operation of claim 16 further comprising:

removing said antenna coupler/connector from said swivel collar.

18. The method of operation of claim 16 further comprising:

capacitively coupling said antenna contact to said swivel collar contact with said antenna in said retracted position, wherein the antenna is allowed to operate with at least limited performance in the retracted position.

19. A system for connection of an antenna to a mobile radio comprising:

a housing;

a swivel collar coupled to the housing and swivelable relative to the housing for swiveling the antenna when in an extended position;

an opening in the swivel collar alignable with a cavity in the housing for retraction of the antenna through the opening into the housing;

a first locking structure on said swivel collar; and

a second locking structure on said housing, wherein said first locking structure and said second locking structure cooperate to fix an angle of rotation of the swivel collar relative to the housing.

* * * * *

US006133891A

United States Patent [19]

Josypenko

[11] **Patent Number:** 6,133,891

[45] **Date of Patent:** Oct. 17, 2000

[54] **QUADRIFILAR HELIX ANTENNA**

[75] Inventor: **Michael J. Josypenko**, Norwich, Conn.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

[21] Appl. No.: **09/173,612**

[22] Filed: **Oct. 13, 1998**

[51] **Int. Cl.**^{7} **H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 343/860

[58] **Field of Search** .... 343/895, 700 MS, 343/850, 853, 865, 859, 860, 893, 906; H01Q 1/36, 1/38

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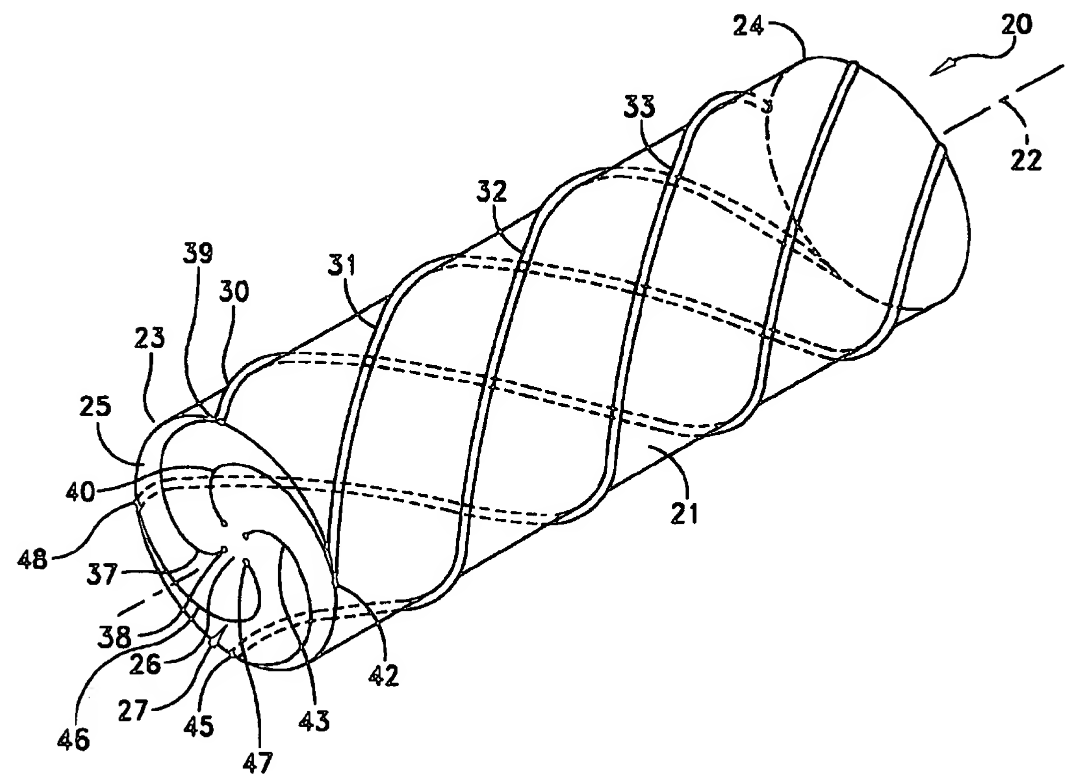
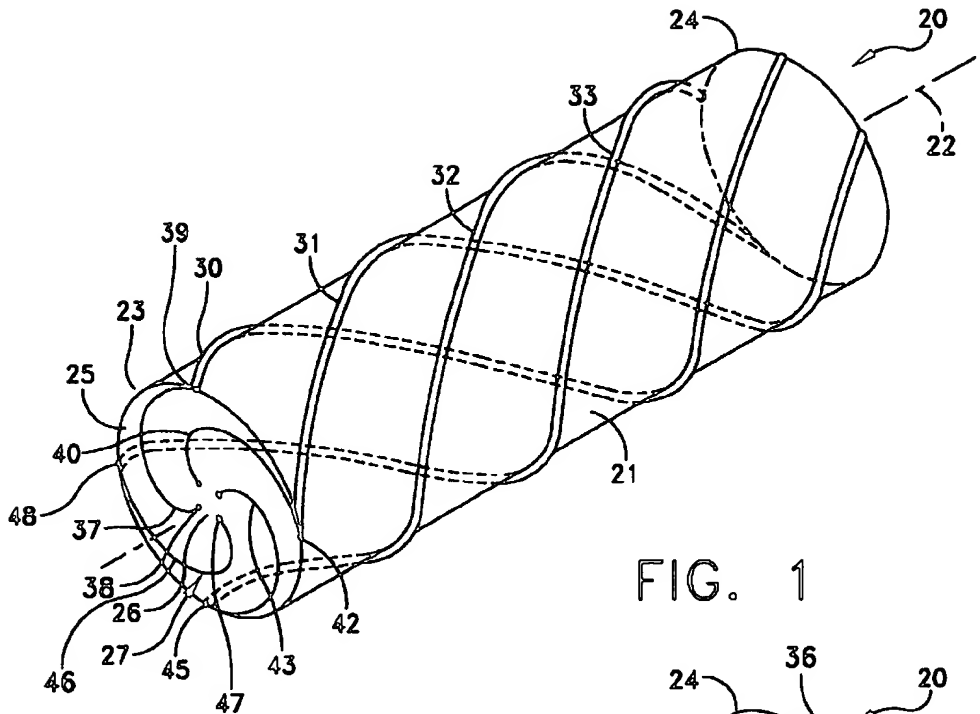
Primary Examiner—Tho Phan
Attorney, Agent, or Firm—Michael J. McGowan; Robert W. Gauthier; Prithvi C. Lall

[57] **ABSTRACT**

A quadrifilar helical antenna is provided having feed points connected to the individual helical antenna elements through a spiral coupling path. The spiral coupling path additionally is wound contrarily to the winding of the helix. Moreover, each path has variable dimensions to provide impedance matching.

20 Claims, 9 Drawing Sheets





24
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FIG. 1

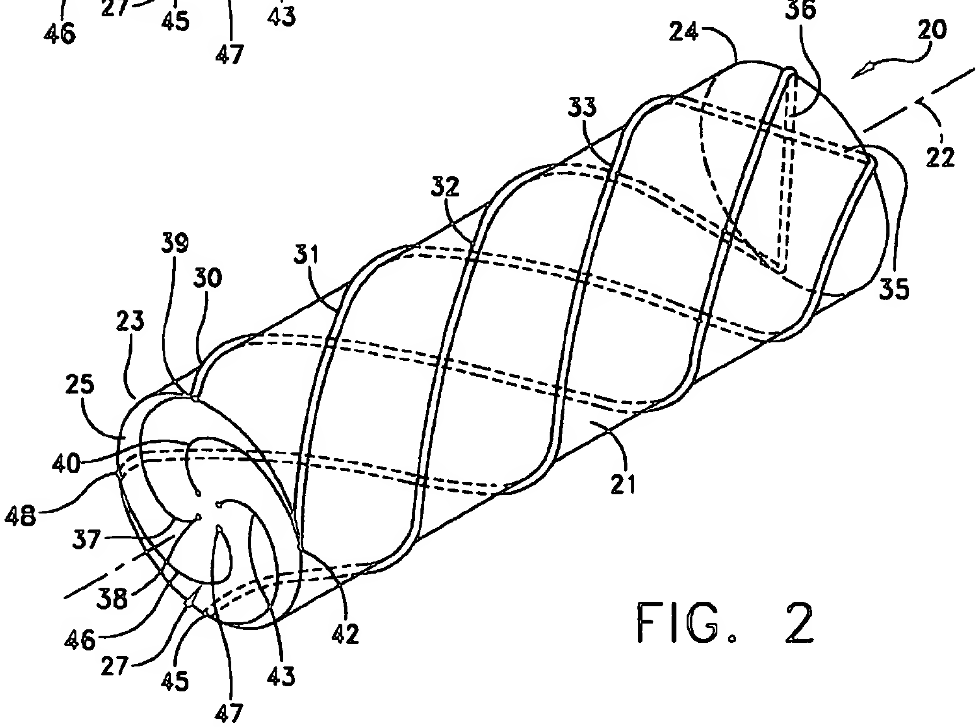

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FIG. 2

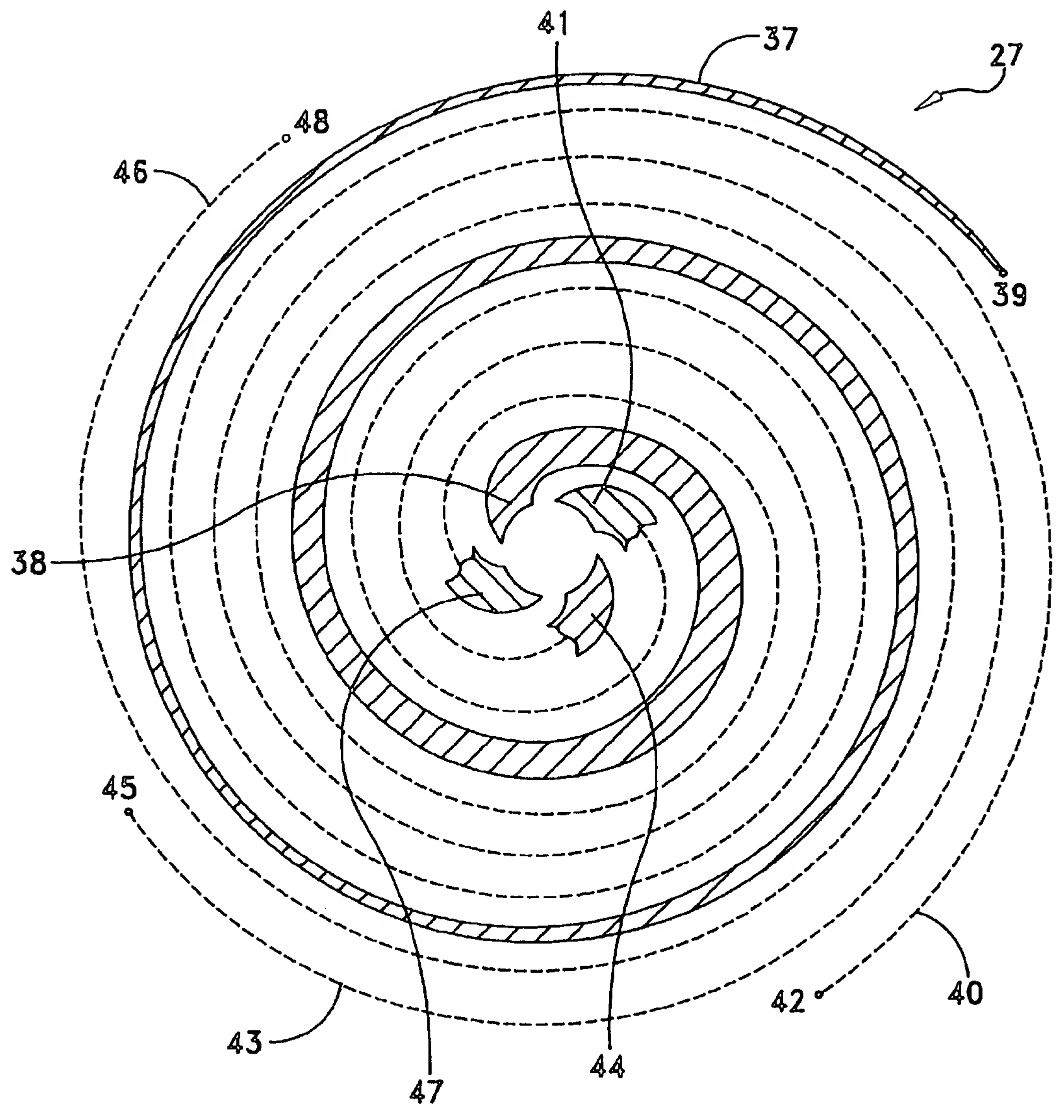


FIG. 3

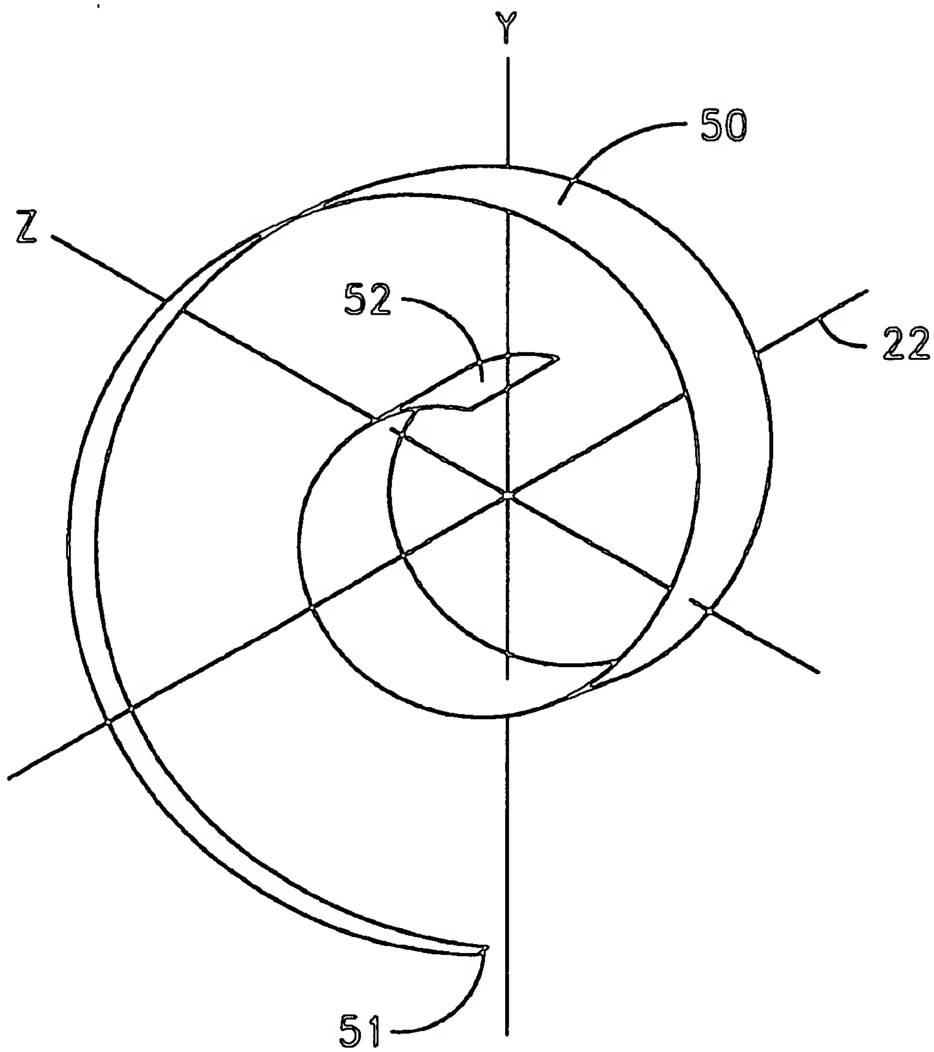
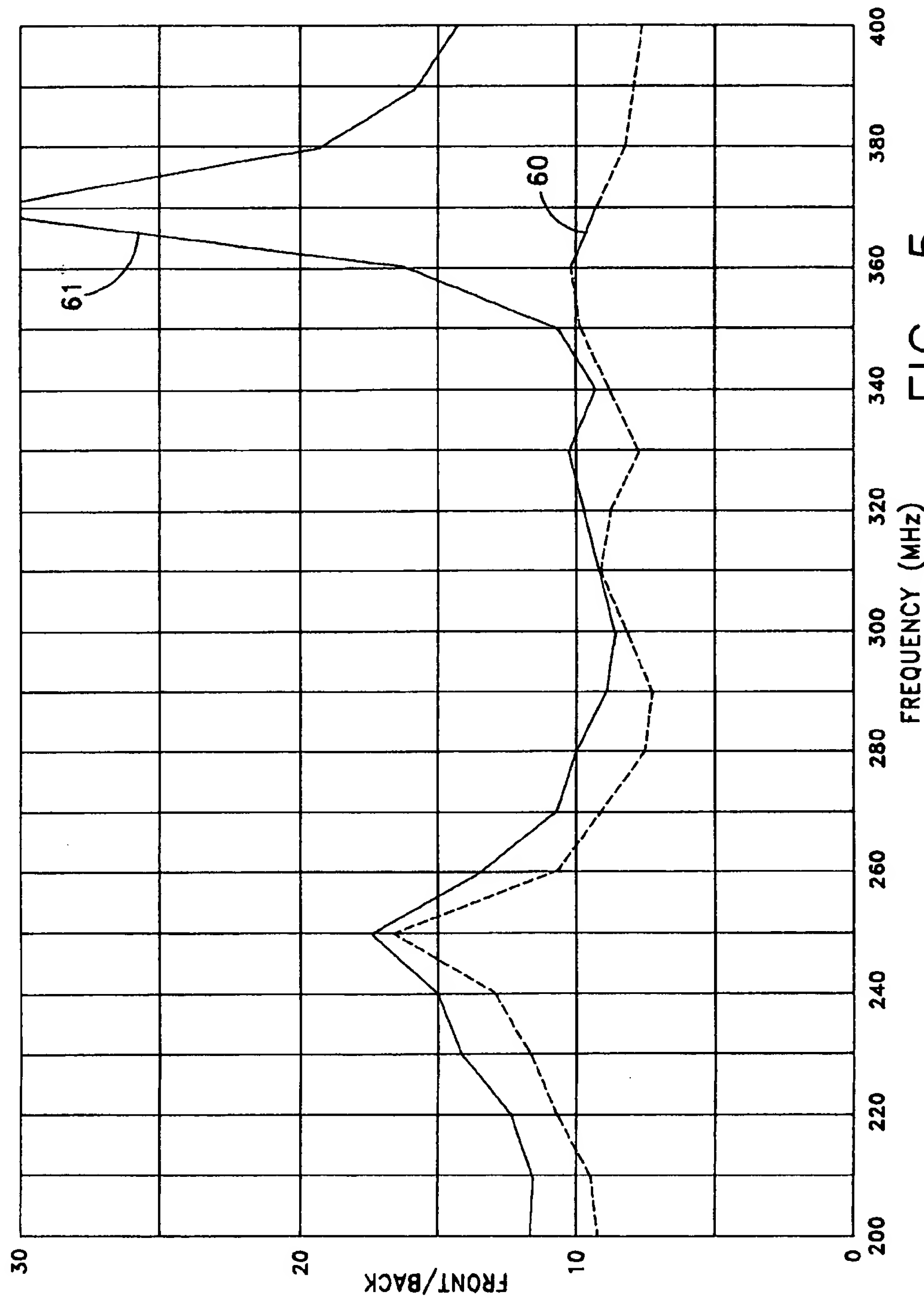


FIG. 4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30
20
10
0
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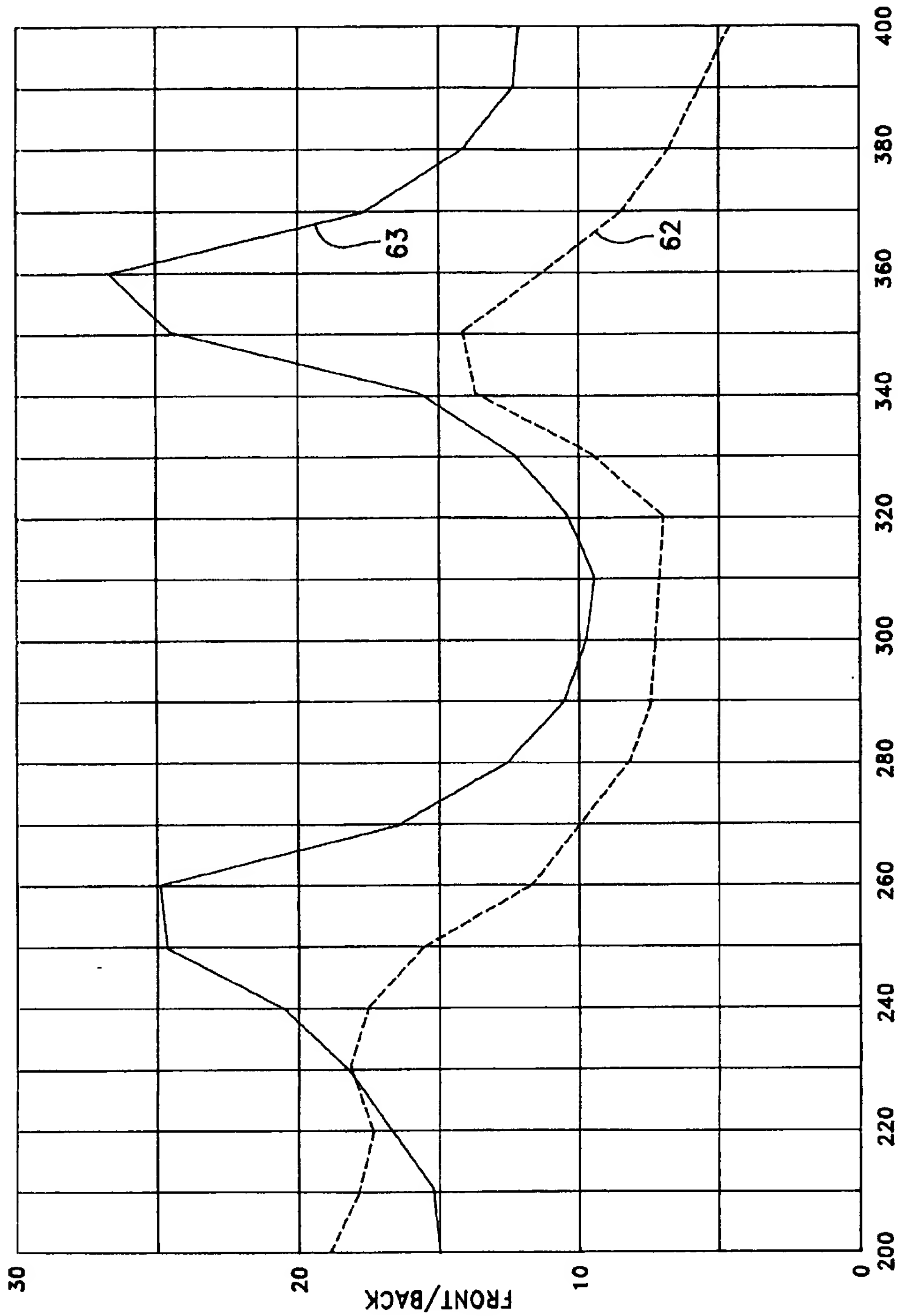
240
260
280
300
320
340
360
380
400
60
61

FIG. 5



FRONT/BACK
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10
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FREQUENCY (MHz)
200
220
240
260
280
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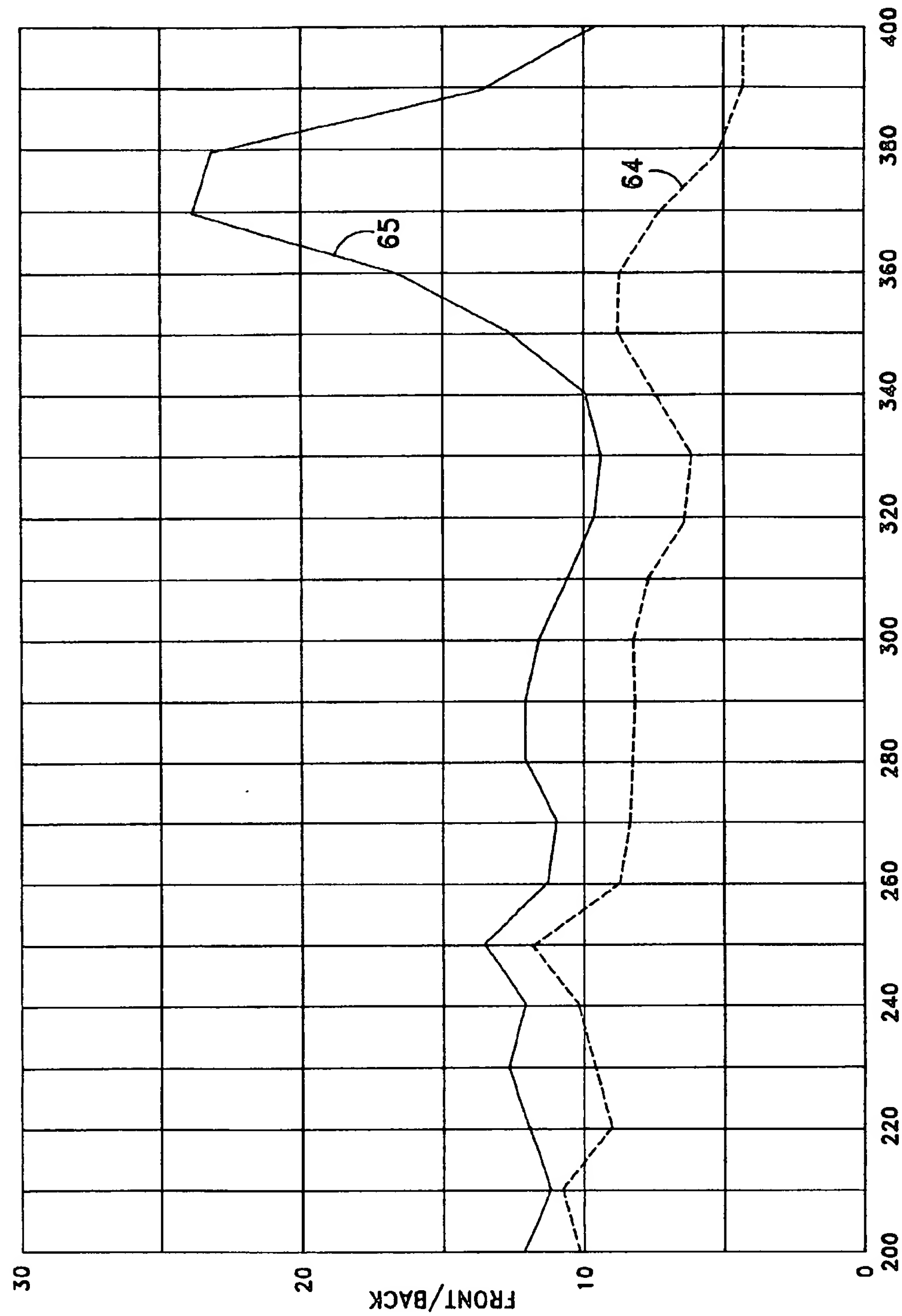
340
360
380
400
63
62

FIG. 6



FRONT/BACK
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10
20
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FREQUENCY (MHz)
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240
260
280
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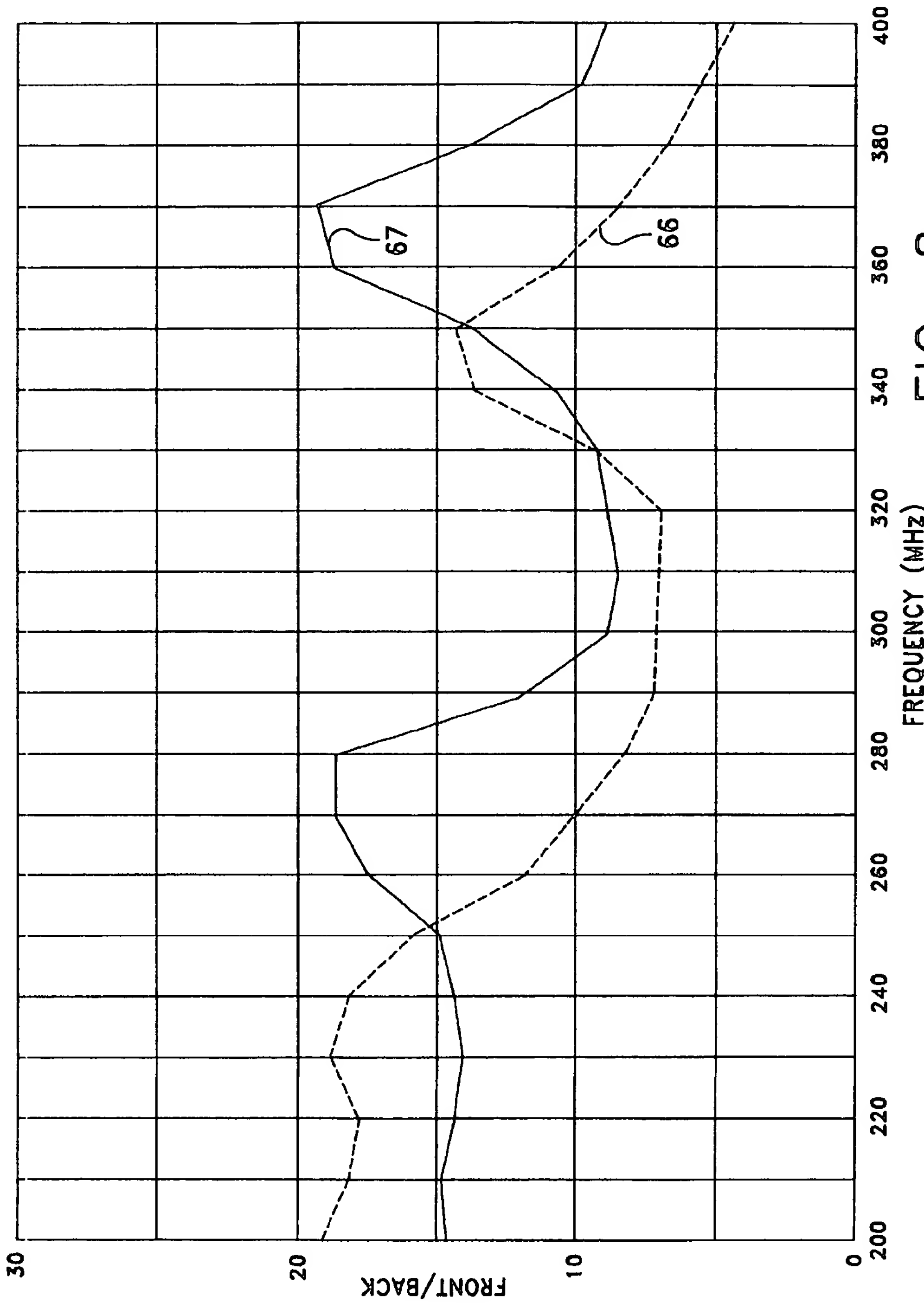
360
380
400
64
65

FIG. 7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240
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340
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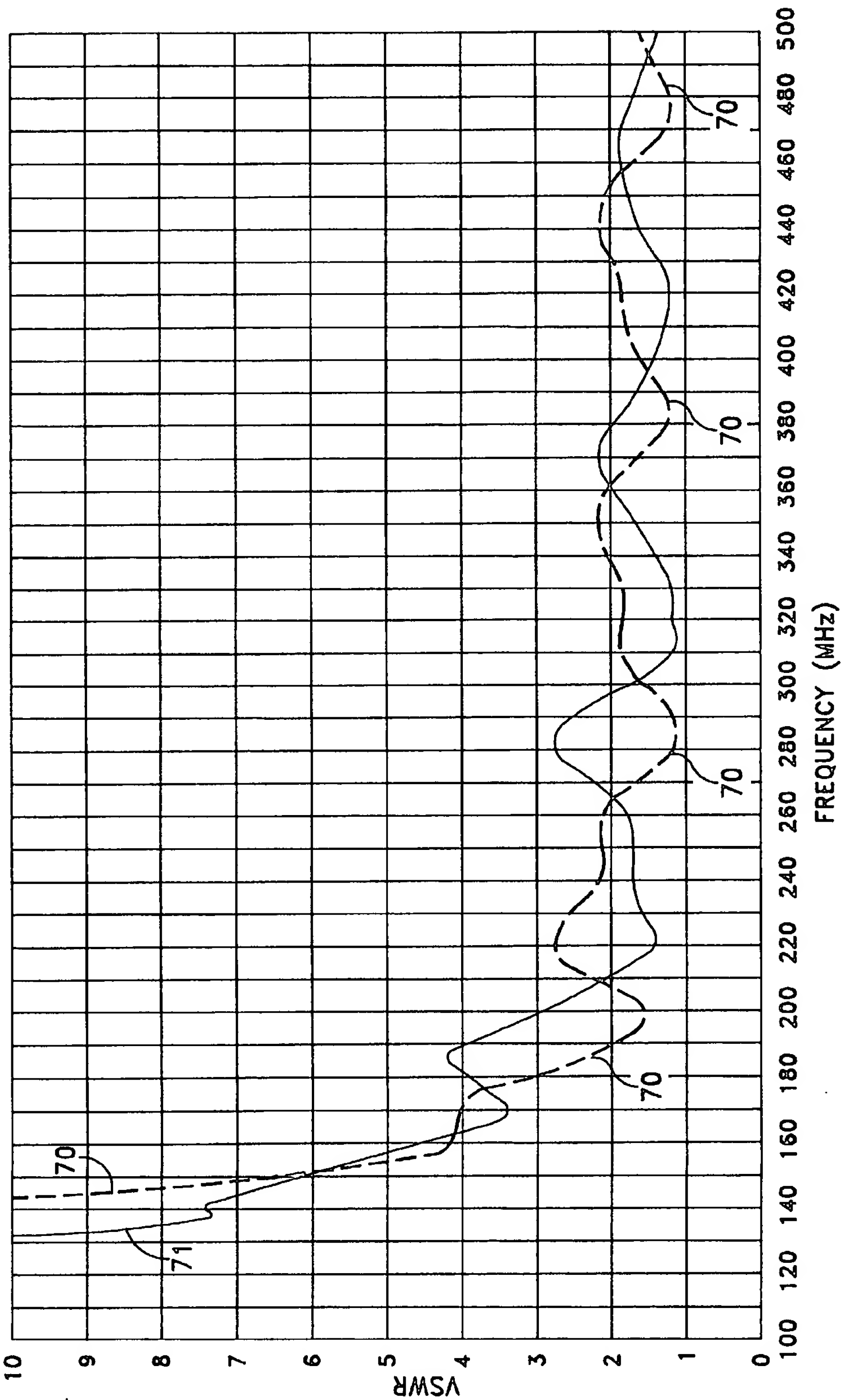
400
67
66

FIG. 8


VSWR
10
9
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6
5
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140
160
180
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340
360
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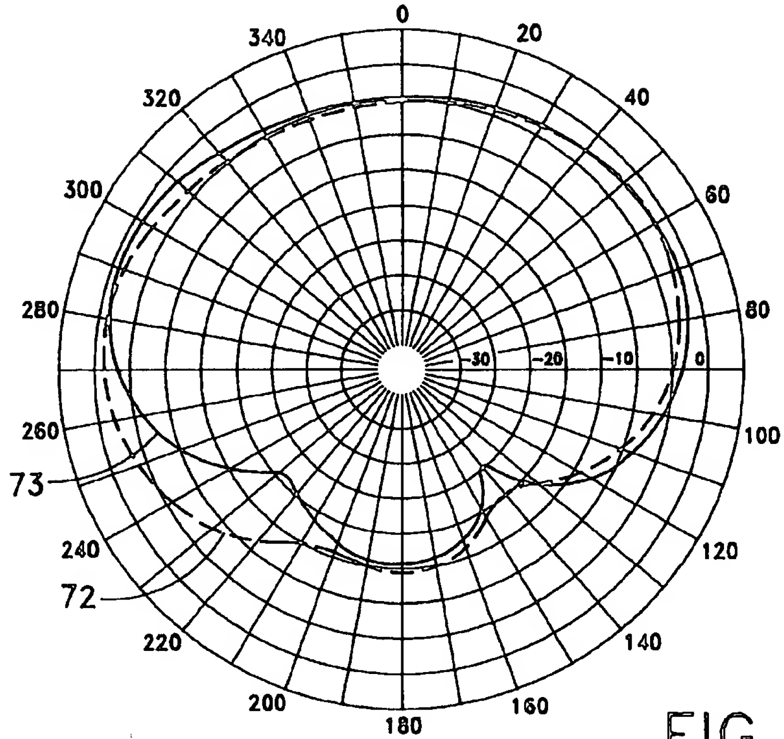
400
420
440
460
480
500
70
71

FIG. 9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72

FIG. 10

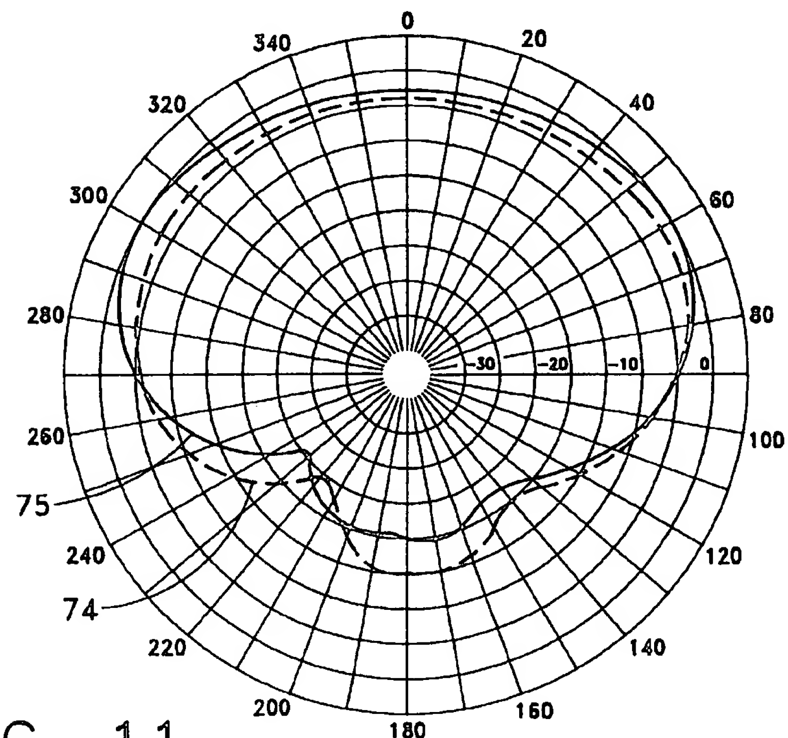
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
-30
-20
-10
0
75
74

FIG. 11

QUADRIFILAR HELIX ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

This invention generally relates to antennas and more specifically to quadrifilar antennas.

(2) Description of the Prior Art

Numerous communication networks utilize omnidirectional antenna systems to establish communications between various stations in the network. In some networks one or more stations may be mobile while others may be fixed land based or satellite stations. Omnidirectional antenna systems are preferred in such applications because alternative highly directional antenna systems become difficult to apply, particularly at a mobile station that may communicate with both fixed land based and satellite stations. In satellite communication applications it is desirable to provide a unidirectional antenna system that is compact yet characterized by a wideband width and a good front-to-back ratio, i.e., the ratio of overhead power to backside power, such that its pattern ideally only occupies the upper hemisphere.

Some prior art omnidirectional antenna systems use an end fed quadrifilar helix antenna for satellite communication and a co-mounted dipole antenna for land based communications. However, each antenna has a limited bandwidth and collectively their performance can be dependent upon antenna position relative to a ground plane. The dipole antenna tends to have no front-to-back ratio which can cause total pattern cancellation when the antenna is mounted on a ship, particularly over low elevation angles. These co-mounted antennas also have spatial requirements that can limit their use in confined areas aboard ships or similar mobile stations.

The following patents disclose helical antennas that exhibit some, but not all, the previously described desirable characteristics:

U.S. Pat. No. 3,599,220 (1971) Demsey

U.S. Pat. No. 3,623,113 (1971) Faigen et al.

U.S. Pat. No. 4,243,993 (1981) Lamberly et al.

U.S. Pat. No. 4,644,366 (1987) Scholz

U.S. Pat. No. 5,053,786 (1991) Silverman et al.

U.S. Pat. No. 5,134,422 (1992) Auriol

U.S. Pat. No. 5,170,176 (1992) Yasunaga et al.

U.S. Pat. No. 5,343,173 (1994) Balodis et al.

U.S. Pat. No. 5,594,461 (1997) O'Neil, Jr.

U.S. Pat. No. 5,635,945 (1997) McConnell

U.S. Pat. No. 3,599,220 to Dempsey discloses a conical, spiral loop antenna comprising a plurality of pairs of spirally wound radiating arms. The radiating arms are wound in the shape of a cone and terminate at one end in a truncated portion. Impedance matching is provided between each of the pairs of radiating arms at the truncated end. A ground plane is provided for each frequency of operation; multiple ground planes are required for multiple frequencies. The primary purpose of this patent is to provide a compact antenna that is tunable. However, it appears that the antenna is generally tuned for a specific frequency.

U.S. Pat. No. 3,623,113 to Faigen et al. discloses a balanced, tunable, helical mono-pole antenna that operates independently of a ground plane. This antenna utilizes a centrally fed, multiple-turn, helical antenna with a single element. End winding shorting means in the form of "top hat"- or "can"-type housings tune the antenna by changing the active electrical length of the antenna. A feed loop is centrally disposed to the helical mono-pole antenna winding to provide a balanced input to the antenna. Although this antenna is compact and can be tuned through a wide bandwidth, it does not provide an omnidirectional radiation pattern.

U.S. Pat. No. 4,243,993 to Lamberty et al discloses a broad band antenna comprising center fed, spiral antenna arms arranged on planar and conical surfaces. Each antenna arm includes one or more choke elements that resonate at a predetermined operating frequency to eliminate or minimize undesired radiation and reception characteristics and provide sum and difference mode operations with both right-hand and left-hand circularly polarized radiation characteristics. Feeding an antenna as disclosed in the Lamberty et al patent with a phased sequence of signals produces a radiation pattern that exhibits a null along an antenna bore sight axis and a maximum field along a cone of revolution about the bore sight axis. Although this antenna has a broad bandwidth and provides circular polarization, it does not provide an omnidirectional radiation pattern.

U.S. Pat. No. 4,644,366 to Scholz discloses a miniature radio transceiver antenna formed as an inductor wrapped about a printed circuit card. A peripheral conductor on one side of the card provides distributed capacitance to the end of the antenna that cancels inductive effects and broadens bandwidth. A peripheral conductor on the opposite side of the card provides a capacitance to ground to tune the antenna to frequency. An unbalanced transmission line connects between one end of the antenna and a tap or feed point to provide impedance matching and tuning. This antenna has a limited bandwidth for a given connection point. Moreover it does not produce an omnidirectional radiation pattern.

U.S. Pat. No. 5,053,786 to Silverman et al. discloses a broad band directional antenna in which two contiguous conductive planar spirals are fed at their center. The antenna is positioned near a cavity to absorb rear lobes in order to improve the front-to-back ratio. Even with this improvement in the front-to-back ratio, the antenna provides a relatively narrow beam pattern having both horizontal and vertical polarization. Apparently, this antenna is designed to operate with a linearly polarized, high gain, narrow beam. Thus the antenna does not provide an omnidirectional radiation pattern or circular polarization. Moreover, by absorbing the rear lobes, the power transmitted into the reserve lobes is lost making the antenna less efficient in radiating during a transmitting mode.

U.S. Pat. No. 5,134,422 to Auriol discloses an antenna with helically wound, equally spaced, radiating elements disposed on a cylindrical surface. Antennas identified as prior art antennas in this reference include helically wound, end driven antenna elements. The other ends of the elements terminate as open circuits. These antennas provide circular polarization, an omnidirectional radiation pattern and a good front-to-back ratio. The Auriol patent is particularly directed to a structure that uses a conductive, meandering strip to connect the driven ends and establish various phase relationships and tuning. This antenna is designed to produce high quality circular polarization, an omnidirectional radiation pattern and a good front-to-back ratio, but only over a narrow frequency band.

In U.S. Pat. No. 5,170,176 (1992) to Yasunaga et al. a quadrifilar helix antenna includes four helix conductors wound around an axis in the same winding direction. Each helix conductor has a linear conductor which is parallel to its axis at either end or both ends of the helix conductor. The purpose of this structure is to reduce the effect of multipath fading due to sea-surface reflection in mobile satellite communications. Although this patent discloses an antenna that provides good front-to-back ratio, the transmission pattern from the antenna is also characterized by essentially forming two major lobes about 60° from the forward direction so it is not truly omni-directional over a hemisphere.

U.S. Pat. No. 5,343,173 (1994) to Balodis et al. discloses a phase shifting network and antenna including a series of helical antenna elements with a phase shifting network defining transmission paths between a radio connection terminal and the antenna elements. Each transmission path phase shifts the signal relative to an adjacent path pairs that are progressively joined at combiner nodes of equal power division by shunt connection line segments.

U.S. Pat. No. 5,594,461 (1997) to O'Neill, Jr. discloses a low loss quadrature matching network for a quadrifilar helix antenna. As in the above-identified Balodis et al. patent, the O'Neill, Jr. patent utilizes microstrip techniques to provide impedance matching in an antenna system.

U.S. Pat. No. 5,635,945 (1997) to McConnell et al. discloses a quadrifilar helix antenna with four conductive elements arranged to define two separate helically twisted loops, one differing slightly in electrical length from the other. The two separate helically twisted loops are connected to each other in a way as to provide impedance matching, electrical phasing, coupling and power distribution for the antenna. The antenna is fed at a tap point on one of the conductive elements determined by an impedance matching network which connects the antenna to a transmission line. Like to foregoing Balodis et al. and O'Neill, Jr. patents, this patent also utilizes microstrip techniques to feed and match through a partly balanced transmission line. As a result the resultant band width is narrow.

The following patent discloses a broadband antenna system:

U.S. Pat. No. 5,257,032 (1993) Diamond et al.

This broadband antenna system includes a frequency-independent antenna coupled to the frequency-dependent antenna, specifically, a spiral antenna and a dipole antenna. In one embodiment the antenna system comprises a dipole or monopole coupled to the inner or outer termination points of a spiral antenna. The spiral antenna acts as a broadband transmission line matching section and adds electrical length to the monopole antenna. Thus, the spiral antenna is stated to minimize the negative effects typically associated with the removal of one of the elements of a stand alone dipole antenna to create a monopole antenna. It is believed that when the dipole antenna is added to the termination points of the spiral antenna, the resulting antenna system extends the low frequency capability of the spiral antenna for linear polarization. It is also felt that the spiral antenna adds electrical length to the dipole antenna and acts as a broadband transmission line matching section so that the spiral antenna enhances receiving capability by producing a maximum signal at the transmission lines. This patent discloses the combination of two types of antennas. However, the combination includes a spiral antenna and either a monopole or dipole antenna. It also appears that the antenna system is directional and not omni-directional over both a broad frequency band and over a hemispherical volume.

Thus there exists a family of quadrifilar helixes that are broadband impedance wise above a certain "cut-in" frequency, and thus are useful for wideband satellite communication (DAMA function of 240 to 320 MHz, other functions at 320 to 410 MHz). Typically these antennas have:

1. a pitch angle of the elements on the helix cylindrical surface from 50° down to roughly 20°;
2. elements that are at least roughly ¾ wavelengths long; and
3. a "cut-in" frequency roughly corresponding to when a turn of an element on the helix cylinder is ½ wavelength long. (This dependence changes some with pitch angle. Above the "cut-in" frequency, the helix has an approximately flat VSWR, around 2:1 or less about the Z_o value of the antenna, and thus the antenna is broadband impedancewise above "cut-in".)

The previous three dimensions translate into a helix diameter of 0.1 to 0.2 wavelengths at "cut-in".

For pitch angles of approximately 30° to 50°, good cardoid shaped patterns exist for satellite communications. Good circular polarization exists down to the horizon since the antenna is greater than 1.5 wavelengths long (2 elements constitute one array of the dual array, quadrifilar antenna) and is at least one turn. At the "cut-in" frequency, the lower pitch 17 angled helixes have sharper patterns. As frequency increases, patterns start to flatten overhead and spread out near the horizon. For a given satellite band to be covered, a tradeoff can be chosen on how sharp the pattern is allowed to be at the bottom of the band and how much it can be spread out by the time the top of the band is reached. This tradeoff is made by choosing where the band should start relative to the "cut-in" frequency and by choosing the pitch angle.

For optimum front-to-back ratio performance, the bottom of the band should start at the "cut-in" frequency. This is because for a given element thickness, backside radiation increases with frequency (the front-to-back ratio decreases with frequency). This decrease of front-to-back ratio with frequency limits the antenna immunity to multipath nulling effects.

SUMMARY OF THE INVENTION

Therefore it is an object of this invention to provide a broad band unidirectional hemispherical coverage antenna.

Another object of this invention is to provide a broad band unidirectional hemispherical coverage antenna with good front-to-back ratio.

Yet another object of this invention is to provide a broad band unidirectional hemispherical coverage antenna that operates with circular polarization.

Yet still another object of this invention is to provide a broad band unidirectional hemispherical coverage antenna that operates with a circular polarization and that exhibits a good front-to-back ratio.

Yet still another object of this invention is to provide a broad band unidirectional hemispherical coverage antenna that is simple to construct.

In accordance with this invention, a helical antenna includes a plurality of antenna elements supported as spaced helices along an antenna axis. Antenna feed points are located proximate the antenna axis at a first end of the helices. A spiral connector between each antenna element and one of the antenna feed points is located between each antenna element and one of the antenna feed points. These spiral connectors lie in a transverse plane at one end of the helices.

In accordance with another object of this invention a quadrifilar helical antenna operates over a frequency bandwidth defined by a minimum operating frequency and includes a cylindrical support extending along an antenna axis between first and second ends thereof. The cylindrical support carries four equiangularly spaced helical antenna elements each having a length of at least ¾ wavelength of the antenna minimum operating frequency. A planar feed end support is located at the first end of the antenna and transverse to the cylindrical support for defining a feed point for each antenna element. Four conductors are arranged in spiral paths that are oppositely wound from the helical antenna elements. Each conductor connects between a feed point and a corresponding antenna element. A pair of radially opposite conductors constitutes a transmission line, thus four conductors, or two pairs constitute two transmission lines. The two transmission lines are fed in phase quadrature at the antenna feed point.

BRIEF DESCRIPTION OF THE DRAWINGS

The appended claims particularly point out and distinctly claim the subject matter of this invention. The various objects, advantages and novel features of this invention will be more fully apparent from a reading of the following detailed description in conjunction with the accompanying drawings in which like reference numerals refer to like parts, and in which:

FIG. 1 depicts an antenna system constructed in accordance with this invention for operating in an open mode;

FIG. 2 depicts an antenna system constructed in accordance with this invention for operating in a shorted mode;

FIG. 3 depicts a transverse section of a particular embodiment of spiral feed point connectors shown in FIG. 1;

FIG. 4 depicts another embodiment of a spiral conductor useful in the connector of FIG. 1;

FIGS. 5 through 8 provide comparisons of the front/back ratios of a prior art antenna and an antenna constructed in accordance with this invention in horizontal and vertical polarization and in open and shorted operating modes;

FIG. 9 depicts the voltage standing wave ratio (VSWR) of an antenna constructed in accordance with this invention operating in the open and shorted modes; and

FIGS. 10 and 11 depict the radiation patterns for horizontally and vertically polarized signals, respectively, to compare the patterns from an antenna embodying this invention. and the corresponding prior art antenna.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts, in schematic form, an antenna 20 constructed in accordance with this invention. A cylindrical support 21 extends along a longitudinal antenna axis 22 between a first or feed end 23 and a second or distal end 24. The cylindrical support 21 is composed of an insulating material that exhibits low losses at the RF frequencies involved, namely between 200 and 500 MHz.

The support additionally includes a planar support 25 at a feed end 23 that is transverse to the cylindrical support 21 and the antenna axis 22. The planar support 25 is also made of a low loss insulating material. The planar support 25 includes an antenna feed point shown generally at 26, for receiving signals from a transmitter or transferring received signals to a receiver (not shown) in quadrature phase and an array 27 of spiral conductors.

In accordance with this invention, the antenna support 21 carries an even number of equiangularly spaced helically wrapped antenna elements 30, 31, 32 and 33, respectively. Typically the plurality will be constituted by four such conductors. Each of the equiangularly spaced elements 30 through 33 will have a length exceeding three-quarters of a wave length (i.e., ¾ λ min) at a minimum operating frequency.

In FIG. 1, each of the antenna elements 30 through 33 terminates in an open circuit at the distal end 24. FIG. 2 depicts the antenna of FIG. 1 with the addition of shorting conductors at the distal end. That is, a diametrically disposed conductor 35 interconnects the distal ends of the antenna elements 31 and 33 and a corresponding diametrically disposed conductor 36 interconnects the distal ends of the antenna elements 30 and 32. As known, but not specifically shown in FIG. 2, the conductors 35 and 36 will be insulated from each other.

Referring to FIGS. 1, 2 and 3, the array 27 at the feed end 23 depicts four spiral conductor paths between the feed point 26 and the conductors. In the embodiment of FIG. 3 a spiral connector 37 extends between an antenna feed point 38 for about two and one-half turns to an antenna element connection 39 with an overall length of at least one-half wavelength at the minimum operating frequency (i.e., 0.5 λmin). Other spiral connectors are shown in partial detail. The result is that each spiral conductor, such as conductor 37, connects between an antenna feed point and a connection at an antenna element. Each pair of radially opposite spiral conductors, i.e., (37;43) and (40,46), constitutes a transmission line, designated T1 and T2, respectively. Thus, the four spiral conductors constitute two transmission lines that are crossed. For the antenna of FIG. 3, the connections are as follows:

Feed Point Phase	Transmission Line	Spiral Conductor	Antenna Feed Point	Antenna Element	Antenna Element Connection
0°	T1	37	38	30	39
270°	T2	40	41	31	42
180°	T1	43	44	32	45
90°	T2	46	47	33	48

Each of the spiral conductors lies along an Archimedean or equiangular spiral path. As is also particularly evident from conductor 37 in FIG. 3, the volume of the conductor increases from the antenna element connection 39 to the antenna feed point 38. Each of the other spiral conductors 40, 43 and 46 have the same characteristic. That is, the volume increases from the outside of the spiral where the connections are made to the antenna elements to the inside of the spiral where each of the conductors attaches as an antenna feed point. The increase in volume may be constituted merely by an increase in width or by an increase in thickness or both. Consequently the input impedance at the antenna element connections (39, 45) and (42, 48) of the spiral transmission lines T1 and T2 will match the input impedance to the antenna elements (30, 32) and (31, 33) while the input impedance at the antenna feed points (38, 44,) and (41, 47) will match the impedance of the two transmission lines (not shown) feeding the RF energy to the antenna. Processes for performing this matching operation by microstrip technology are well known in the art.

The variation in volume is depicted as a linear function in FIG. 3. The variation could be exponential or follow other mathematical rules. Moreover, in FIG. 3, the conductors could have a variable width and constant thickness.

At the antenna feed point 26, the structure shown in FIG. 3 has a practical lowest input impedance of about 100 ohms, which feeds nicely into the balanced 100 ohm port of a 50 to 100 ohm, 180° power splitter (not shown). Two such splitters connected to a 90° power splitter will allow a 50 ohm line to connect to the antenna in phase quadrature. An alternative spiral that can obtain exactly 100 ohms or much lower values of input impedance is shown in FIG. 4. The spiral is converted to three dimensions having conductors that have a variable depth along the helix axis 22. In such a structure an air foam spacer would separate the conductors. The conductor 50 would have a high impedance at an end 51 and a low impedance at an end 52. This is believed to provide more evenly spaced current distributions across the element surface, thereby reducing ohmic loss in the signal and consequently producing lower antenna losses.

As shown in FIGS. 1 and 2, the current path through the spiral connector array 27 and the current path through the antenna elements 30 through 33 are in reverse directions when viewed along the antenna axis 22. That is, viewed from the feed end 23, the current paths for the array are clockwise about the axis while the current paths for the antenna elements 30 through 33 are counterclockwise. This reverse direction is important in that backside radiation increases as the elements are changed from reverse spiral arms to radial arms to same direction spiral arms. It is believed that the small amount of circular polarized radiation produced on the backside of the antenna pattern by the helical elements is canceled to a large extent by circular polarized radiation in the opposite direction produced by connector array 27.

The performance and improvements over prior art antennas can be better appreciated by referring to the following example: An antenna according to this invention has the cylindrical support of a 9" diameter and 39.25" length. The diameter of the antenna elements 30 through 33 is 0.5 inches and the pitch angle for these elements is 42.50°. Each spiral element, such as element 31, is formed of a 0.003" copper tape laid on a 0.003" mylar substrate. The prior art example has the same construction except for the spiral conductors. In the prior art example the interconnection from the feed point 26 to each antenna element is a radial feed path, such as shown in U.S. Pat. No. 5,635,945. For the above example, the RF frequencies involved are between 200 and 500 MHz. Changing the size of the antenna will allow other frequency ranges.

FIG. 5 compares the horizontal polarization front-to-back ratios of the spiral fed, open-ended antenna shown in FIG. 1 fed in backfire mode, i.e., the main pattern beam comes off of the feed and of the antenna, to the performance of a prior art system wherein the spiral feed is replaced by radial feeds. Specifically, Graph 60 in FIG. 5 depicts the radially-fed prior art antenna to the performance of the spiral fed open-ended antenna represented by Graph 61. It will be apparent that the front-to-back ratio is improved over the entire frequency band represented in FIG. 4 from 200–400 MHz.

FIG. 6 provides a similar comparison with vertical polarization. In FIG. 6 Graph 62 represents the radial-fed antenna and Graph 63 represents the front-to-back ratios for the spiral fed antenna of FIG. 1. With the exception of a portion of the low end of the frequency range (i.e, 200–230 MHz) front-to-back ratios are improved over the entire range of the frequencies.

FIG. 7 compares the spiral fed, shorted antenna of FIG. 2 with a comparable prior art antenna in which the spiral feeds are replaced with radial feeds. More particularly, FIG. 7 depicts the front-to-back ratios for horizontally polarized signals and FIG. 8 for vertically polarized signals. In FIG. 7 graph 64 represents front-to-back ratios for the prior art antenna; graph 65 for the antenna of FIG. 2. In FIG. 8, graph 66 represents front-to-back ratios for the prior art antenna; graph 67 for the antenna of FIG. 2. Both these graphs demonstrate that front-to-back ratios are improved over the entire spectrum by the application of this invention.

FIG. 9 depicts the VSWR of the antenna as shown in FIGS. 1 and 2. Graph 70 depicts the VSWR of the antenna in FIG. 1; Graph 71, the antenna in FIG. 2. The VSWR reaches an acceptable level at about 200 MHz and remains at acceptable levels to at least 500 MHz. In addition, it will be apparent that whether the antennas are operated in the open or shorted forms of FIGS. 1 and 2 the VSWR's have about the same values. Therefore, antenna performance from this aspect seems unaffected by being in the open or shorted versions.

FIGS. 10 and 11 compare sample radiation patterns for the antennas in FIGS. 1 and 2 for both horizontal and vertical polarizations at 270 MHz. More specifically, FIG. 10 depicts the patterns for horizontal polarization, Graph 72 depicting the radiation pattern for the prior art antenna and Graph 73 the antenna of FIG. 1. In FIG. 11, Graph 74 depicts the radiation pattern for vertically polarized signals for the prior art antenna and Graph 75 for the antenna in FIG. 1. These comparisons show that most of the radiation from the antenna is in the forward direction. Moreover, the comparisons show that at this particular frequency the front-to-back ratios, i.e., the ratio of gain at 0° to gain at 180°, are improved throughout. Further, analyses for other frequencies depict that this characteristic continues throughout the spectrum.

In summary, the antennas depicted schematically in FIGS. 1 and 2 operate as do prior art antennas over a wide frequency range with acceptable levels of VSWR in both an open mode and shorted mode. However, the antennas of the present invention improve front-to-back ratios are improved essentially over the entire frequency range in all modes and in both horizontal and vertical polarizations. Moreover, the radiation patterns from these are improved. It will be apparent that this antenna has been described with respect to two particular embodiments and again in schematic form. This specific implementation of this invention may take different forms. Particularly, several alternative methods for feeding the antenna elements through the spiral path have been disclosed. It is the object of the appended claims to cover all such variations and modifications as come under the true spirit and scope of this invention.

What is claimed is:

1. A helical antenna comprising:

a given plurality of antenna elements supported as spaced helices along an antenna axis;

antenna feed points proximate the antenna axis at a first end of the helices; and

a spiral conductor line between each antenna element and one of said antenna feed points for providing an impedance matching signal path, said spiral conductor lines lying in a common plane transverse to the antenna axis.

2. A helical antenna as recited in claim 1 wherein said given plurality of antenna elements is an even number whereby a pair of antenna elements terminate with free ends at a second end of the helices at diametrically opposed positions.

3. A helical antenna as recited in claim 2 additionally comprising a connector for electrically connecting each pair of diametrically opposed free ends at the second end of the helices.

4. A helical antenna as recited in claim 1 wherein each spiral conductor line has a variable cross section along its length.

5. A helical antenna as recited in claim 4 wherein said variable cross section diminishes linearly from said feed point to its respective antenna element.

6. A helical antenna as recited in claim 4 wherein said variable cross section diminishes exponentially from said feed point to its respective antenna element.

7. A helical antenna as recited in claim 4 wherein said variable cross section has a constant dimension in one plane and a variable dimension in an orthogonal plane.

8. A helical antenna as recited in claim 7 wherein each said spiral conductor line has a constant thickness parallel to the antenna axis and a variable width in the transverse plane.

9. A helical antenna as recited in claim 7 wherein each said spiral conductor line has a constant width in the transverse plane and a variable thickness parallel to the antenna axis.

10. A helical antenna as recited in claim 1 wherein:

each said antenna element has a length of at least ¾ of a wavelength of the minimum antenna operating frequency; and

each said spiral conductor line has a length of at least ½ wavelength of the minimum antenna operating frequency.

11. A helical antenna as recited in claim 1 wherein said plurality of antenna elements is an even number whereby a pair of antenna elements are connected to spiral conductor lines at diametrically opposed positions.

12. A helical antenna as recited in claim 11 further comprising a plurality of transmission lines, each transmission line connected to a pair of antenna feeds corresponding to the diameterically opposed pair of antenna elements, wherein each corresponding pair of spiral conductor lines has a configuration that provides a first characteristic impedance that matches a characteristic impedance of the corresponding antenna elements at the connections thereto and further provides a second characteristic impedance for matching a characteristic impedance of the transmission line connected thereto.

13. A quadrifilar helical antenna for operating over a frequency bandwidth defined by a minimum operating frequency comprising:

a cylindrical support extending along an antenna axis between first and second ends thereof;

four equiangularly spaced helical antenna elements extending along said support, each said antenna element having a length of at least ¾ wavelength of the antenna minimum operating frequency;

a planar feed end support at the first end of and transverse to said cylindrical support for defining a feed point for each antenna element;

four conductors arranged in spaced spiral paths, said spiral being oppositely wound from said helical antenna elements, each said conductor connecting between a feed point and a corresponding antenna element.

14. A quadrifilar helical antenna as recited in claim 13 wherein each antenna element extends to a free end adjacent the second end of said cylindrical support.

15. A quadrifilar helical antenna as recited in claim 14 additionally comprising a connector for electrically connecting each pair of diametrically opposed free ends.

16. A quadrifilar helical antenna as recited in claim 13 wherein each of said spiral conductors has a cross-section that varies diminishingly from said feed point to its respective antenna element.

17. A quadrifilar helical antenna as recited in claim 16 wherein each of said spiral conductors has a cross-section that varies in a dimension parallel to said antenna axis.

18. A quadrifilar helical antenna as recited in claim 16 wherein each of said spiral conductors has a cross-section that varies in a dimension parallel to said antenna axis.

19. A quadrifilar helical antenna as recited in claim 13 wherein each of said spiral conductors has a cross-section that varies linearly, the cross-section diminishing from said feed point to its respective antenna element.

20. A quadrifilar helical antenna as recited in claim 13 wherein each of said spiral conductors has a cross-section that varies diminishes exponentially, the cross-section diminishing from said feed point to its respective antenna element.

* * * * *

US006088000A

United States Patent [19]

Ho

[11] **Patent Number: 6,088,000**

[45] **Date of Patent: Jul. 11, 2000**

[54] **QUADRIFILAR TAPERED SLOT ANTENNA**

[75] Inventor: **Chien H. Ho**, San Diego, Calif.

[73] Assignee: **Garmin Corporation**, Taipei, Taiwan

[21] Appl. No.: **09/263,174**

[22] Filed: **Mar. 5, 1999**

[51] **Int. Cl.**^{7} **H01Q 13/10**; H01Q 1/36

[52] **U.S. Cl.** **343/770**; 343/767; 343/895

[58] **Field of Search** .... 343/767, 768, 343/770, 895, 700 MS; H01Q 13/10, 1/36

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5,955,997	9/1999	Ho et al.	343/767

Primary Examiner—Don Wong
Assistant Examiner—Hoang Nguyen
Attorney, Agent, or Firm—Shook, Hardy & Bacon L.L.P.

[57] **ABSTRACT**

A tapered slot quadrifilar antenna for GPS receivers. The antenna has a cylindrical dielectric body covered with a conductive coating. Four helical slots are formed in the antenna and extend around one half of its circumference to provide a right hand circular polarization for receiving GPS signals. A microstrip feed system is provided and is arranged to create balanced currents along both sides of each slot so that the impedance transformation is not adversely affected. Each slot has a narrow upper end and a wide lower end and a progressively greater width from the narrow end to the wide end.

21 Claims, 2 Drawing Sheets

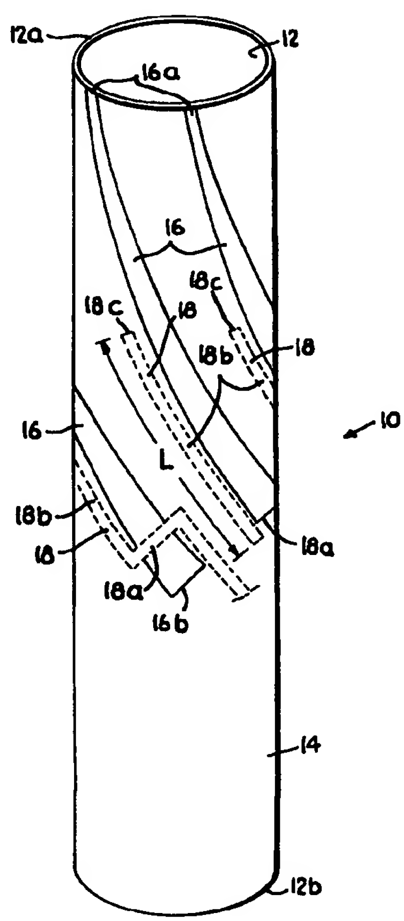
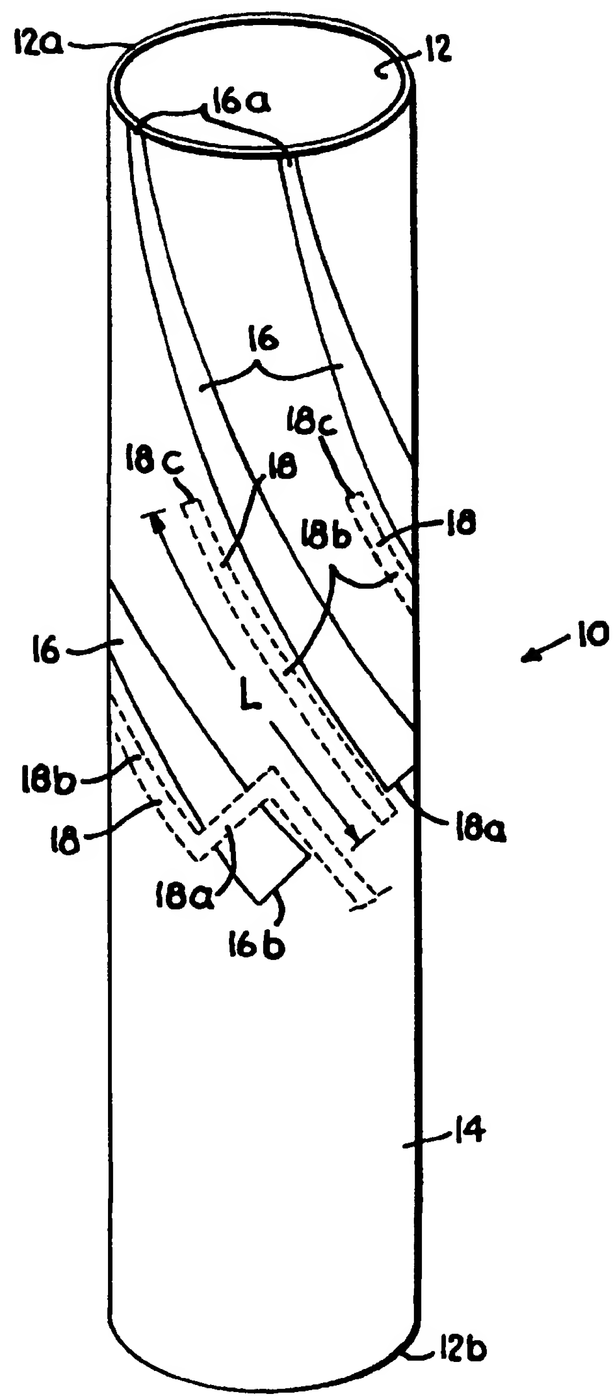


FIG. 1.



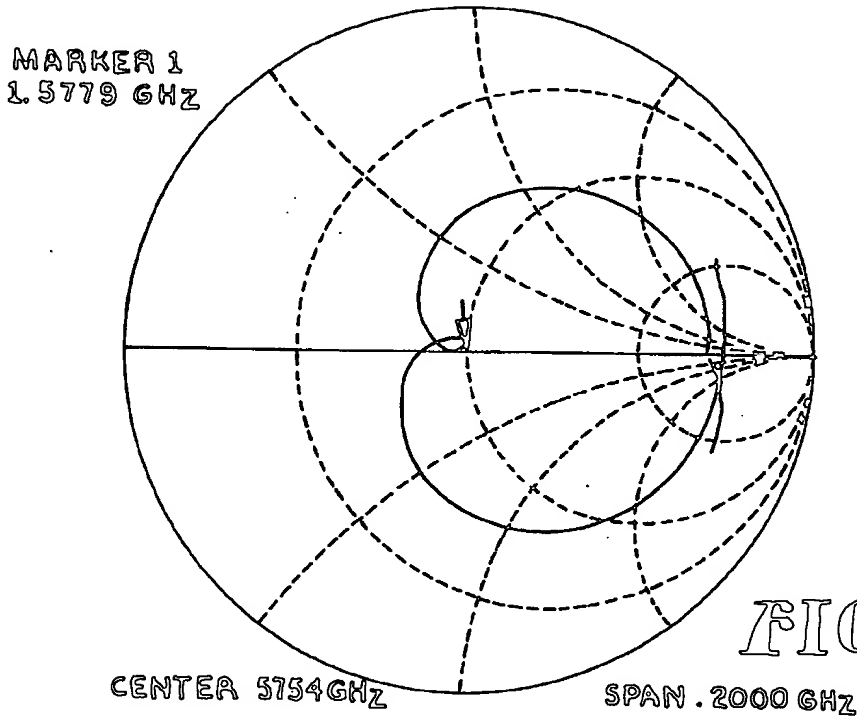
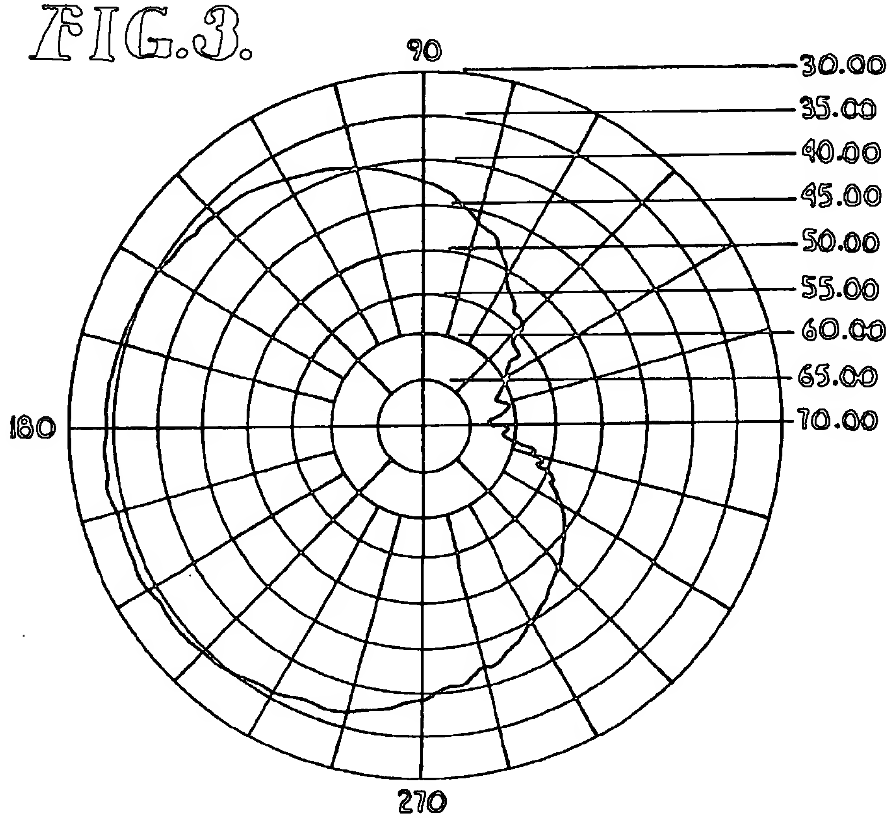

MARKER 1
1.5779 GHz
CENTER 5754GHz
SPAN .2000 GHz

FIG. 2.

FIG. 3.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70.00
180
270

QUADRIFILAR TAPERED SLOT ANTENNA

FIELD OF THE INVENTION

This invention relates generally to cylindrical slot antennas and deals more particularly with a slot antenna in which helical slots are tapered in order to enhance the horizon coverage for receiving low elevation signals such as those emitted from GPS satellites.

BACKGROUND OF THE INVENTION

In recent years, the global positioning system (GPS) has been instrumental in advancing the practical utility of satellite communications in a variety of applications. In order to take full advantage of the capabilities offered by GPS satellite transmissions, antennas that provide a right hand circular polarization are necessary. Good coverage near the horizon is also necessary so that low elevation satellites can be effectively tracked. Antennas having crossing slots have been proposed, as have a variety of cylindrical slot antennas. Slot antennas typically include slots that are uniform in width and are used with microstrip feed systems. Cylindrical slot antennas have many advantageous characteristics, including broad beam pattern production, light weight, amenability to mass production, and simple feeding and matching techniques. However, the cylindrical slot antennas that have been proposed in the past have not been entirely satisfactory with respect to their ability to provide effective horizon coverage of low elevation signals.

SUMMARY OF THE INVENTION

Accordingly, it is evident that a need exists for a GPS antenna that is improved in its ability to track satellites at low angles of elevation. It is the principal goal of the present invention to meet that need. The invention is also directed to a GPS antenna that exhibits good impedance matching and a good front/back ratio.

More specifically, it is an object of the invention to provide an antenna that is improved functionally and which takes advantage of the practical benefits of slot antennas, such as suitability for low cost mass production, lightweight, a compact configuration, broad beam pattern capabilities, and simplicity in feeding and matching techniques.

In accordance with the present invention, a resonant quadrifilar structure is provided by forming four tapered helical slots in a cylindrical antenna in order to improve the antenna tracking near the horizon. The base of the antenna is formed as a cylinder which is preferably constructed from a dielectric laminate. The outer surface of the cylinder is coated with a conductive material that provides an electrical ground for a microstrip feed line system. The slots are etched in the coating starting at one end of the cylinder and terminating well short of the opposite end. Each slot extends around approximately one half of the circumference of the cylinder.

Each slot is tapered from bottom to top to provide a more uniform current flow and a loop-dipole radiation pattern. This in turn improves the horizon coverage and maintains a good cardioid shaped radiation pattern. Each slot has its narrow top end at the upper edge of the antenna and its wide end shorted at a location well away from the bottom end of the antenna. Each slot progressively widens from its narrow upper end to its wide lower end.

Microstrip feed lines are connected with an electric circuit and include transverse portions that cross the slots at right angles. Longitudinal portions of the feed lines extend from the transverse portions and are generally parallel to the tapered slots. The end of each feed line terminates in an open circuit at the feed point. The longitudinal portions of the slots have lengths that are equal to about one fourth wavelength of the GPS signals that are received. The resonant quadrifilar structure provides the necessary right hand circular polarization and increases the radiation coverage in the horizontal plane, while providing enhanced coverage near the horizon.

Other and further objects of the invention, together with the features of novelty appurtenant thereto, will appear in the course of the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which form a part of the specification and are to be read in conjunction therewith and in which like reference numerals are used to indicate like parts in the various views:

FIG. 1 is a perspective view of a quadrifilar tapered slot antenna constructed according to a preferred embodiment of the present invention, with microstrip feed lines being only partially shown for purposes of clarity;

FIG. 2 is a diagrammatic view showing the measured frequency response of the input impedance of the quadrifilar slot antenna of the present invention; and

FIG. 3 is a diagrammatic view showing the radiation pattern of the slot antenna of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings in more detail and initially to FIG. 1, numeral **10** generally designates a printed quarter wavelength quadrifilar slot antenna constructed in accordance with the present invention. The antenna **10** has a body **12** which may be constructed of a dielectric laminate having the shape of a hollow cylinder. The body **12** should be nonconductive and is preferably a dielectric constructed of KAPTON material (KAPTON is a registered trademark of E. I. DuPont Nemours & Co.). Other suitable materials can be used to construct the body **12** of the antenna.

The cylindrical outer surface of the body **12** is provided with a thin coating **14** which coats the outside of the antenna **10**. The coating **14** is constructed of a suitable electrically conductive material such as a metal. The coating **14** provides an electrical ground for microstrip feed lines which will subsequently be described.

The antenna **10** may have a cap (not shown) which includes a conductive material that is in contact with the coating **14** when the cap is in place on the top end **12*a*** of the antenna body **12**.

Four helical radiating slots **16** are formed through the antenna **10** and extend through the body **12** and the coating **14**. Each of the radiating slots **16** has a spiral or helical configuration and extends into the top end of the antenna **10**. Each slot **16** extends helically around approximately one-half of the circumference of the antenna **10** and terminates in a bottom end that is located well above the lower end **12*b*** of the body **12**. The slots **16** are spaced equidistantly apart and are parallel to one another. The slots **16** may be etched in the coating **14** using conventional techniques.

It is a particular feature of the invention that each of the slots **16** is tapered. Each slot **16** has a relatively narrow upper end **1 6*a*** that is an open end adjacent to the top end **12*a*** of the antenna body **12**. The opposite or lower end **16*b*** of each slot is a shorted end which is considerably wider than the

upper end *16a*. End *16b* is located well above the lower end *12b* of the body **12**. Each slot **16** gradually and progressively widens as it extends in a helical curve from the narrow upper end **16a** to the wide lower end **16b**.

A conventional hybrid electrical circuit (not shown) is connected with microstrip feed lines which are identified by numeral **18**. Each of the slots **16** is provided with one of the feed lines **18**. The lower end portion of each feed line **18** connects with the hybrid circuit and the lower portions of the feed lines **18** extend upwardly slightly above the wide lower ends **16b** of the corresponding slots **16**. Each feed line **18** includes a relatively short transverse portion **18a** which extends across the corresponding slot **16** at a right angle to the longitudinal axis of the slot. Each of the transverse portions **18a** extends from the upper end of the leg of the feed line **18** which connects with the hybrid electrical circuit.

Each feed line **18** also includes a longitudinal portion **18b** which extends generally upwardly from the transverse portion **18a**. Each longitudinal portion **18b** extends along and parallel to the corresponding slot **16**. The longitudinal portion **18b** of each feed line **18** terminates in an end **18c** which is an open circuit providing the feed point. The end **18c** is spaced from the transverse portion **18a** of the same feed line by a distance L which defines the length of the longitudinal portion **18b**. The distance L is equal to approximately ¼ λ, where λ is the wavelength of the GPS signals which the antenna is to receive.

The arrangement of the feed lines **18** relative to the slots **16** results in balanced current flowing on both sides of each of the radiating slots **16** so that there is only minimal effect on the impedance transformation. At the same time, the tapered quadrifilar structure provides the right hand circular polarization which is necessary and improves the horizon coverage and VSWR.

FIG. **2** shows the measured frequency response of the input impedance for the antenna **10**. The antenna is resonant at 1.5754 Ghz (the GPS frequency) with input impedance of 49+j2 Ω.

The return loss at the center frequency is greater than 30 dB. The cardioid radiation pattern of the antenna **10** is depicted in FIG. **3**. The half power beam width is more than 120° and the front/back ratio is greater than 20 dB. This is generally considered to be a favorable ratio for the resistance of multipath signals from the ground.

The quarter wavelength quadrifilar slot antenna **10** was verified by conducting a field test using a Garmin GPS 90™ receiver. The test was conducted under a satellite geometry with Position Dilution of Precision (PDOP) of 70 ft. The results of the test indicate that satellites **2**, **7**, **15**, **19**, and **27** located within the axis angle of θ=±45° have calibrated signal scales of 10, 7, 7, 8, and 9, corresponding to receiver phase noise 53 dB, 47 dB, 47 dB, and 51 dB, respectively.

Satellites **13**, **26**, and **31** located outside the axis angle of θ=±45° have calibrated signal scales of 6, 7, and 5, corresponding to receiver phase noise of 45 dB, 47 dB, and 43 dB respectively. These test results indicate a radiation pattern coverage of the antenna **10** that permits it to effectively track satellites near the horizon at very low elevation angles.

The construction of the antenna **10** and the pattern and relationship of the slots **16** and feed lines **18** result in good input impedance matching, a good front/back ratio, and improved horizon coverage. At the same time, the known advantages of cylindrical slot antennas are achieved, including low cost manufacturing, light weight, compact size, ease of fabrication and assembly, and simple feeding and matching techniques.

From the foregoing it will be seen that this invention is one well adapted to attain all ends and objects hereinabove set forth together with the other advantages which are obvious and which are inherent to the structure.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

Since many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative, and not in a limiting sense.

Having thus described the invention, what is claimed is:

1. An antenna for electromagnetic signals, comprising:
   - a nonconductive cylindrical body having an outside surface;
   - a conductive coating on said outside surface of said body;
   - a plurality of slots in said coating extending in a helical pattern around said body, each slot having opposite ends with one end having a lesser width dimension across the slot than the opposite end; and
   - a feed line for each slot having a transverse portion extending across the slot and a longitudinal portion extending generally along and parallel thereto.

2. An antenna as set forth in claim **1**, wherein said body has upper and lower ends and said one end of each slot is closer to said upper end than to said lower end.

3. An antenna as set forth in claim **2**, wherein said one end of each slot is adjacent to said upper end of the body.

4. An antenna as set forth in claim **3**, wherein said opposite end of each slot is spaced from said lower end of the body.

5. An antenna as set forth in claim **4**, wherein said slots are spaced substantially equidistantly apart and are substantially parallel.

6. An antenna as set forth in claim **1**, wherein said slots are spaced substantially equidistantly apart and are substantially parallel.

7. An antenna as set forth in claim **1**, wherein said cylindrical body comprises a dielectric.

8. An antenna as set forth in claim **1**, wherein said cylindrical body comprises a laminate.

9. An antenna as set forth in claim **1**, wherein said coating provides an electrical ground for said feed lines.

10. An antenna as set forth in claim **1**, wherein said longitudinal portion of each feed line terminates in an open circuit.

11. An antenna as set forth in claim **1**, wherein said longitudinal portion of each feed line has an end and a length L between the transverse portion thereof and said end thereof, said length L being approximately ¼ λ where λ is the wavelength of a GPS signal to be received by the antenna.

12. An antenna as set forth in claim **11**, wherein said end of the longitudinal portion of each feed line terminates in an open circuit.

13. An antenna as set forth in claim **1**, wherein each slot extends helically around said body approximately one half of the circumference thereof.

14. An antenna as set forth in claim **1**, wherein the transverse portion of each feed line is oriented substantially perpendicular to the corresponding slot.

15. An antenna as set forth in claim **14**, wherein said longitudinal portion of each feed line has an end and a length L between the transverse portion thereof and said end

thereof, said length L being approximately ¼ λ where λ is the wavelength of a GPS signal to be received by the antenna.

16. An antenna as set forth in claim **15**, wherein said end of the longitudinal portion of each feed line terminates in an open circuit.

17. A cylindrical slot antenna, comprising:

a nonconductive cylindrical body having opposite first and second ends and an outside surface;

a conductive coating on said outside surface;

a plurality of slots in said coating each having a narrow end adjacent said first end of said body and a wide end spaced from said second end of said body, each slot extending around said body in a helical pattern and having a greater width at said wide end than at said narrow end; and

a feed line for each slot connected with an electric circuit, each feed line having a transverse portion extending across the corresponding slot and a longitudinal portion extending generally along and parallel thereto.

18. An antenna as set forth in claim **17**, wherein said slots are spaced substantially equidistantly apart and are substantially parallel.

19. An antenna as set forth in claim **18**, wherein each slot extends helically around said body approximately one half of the circumference thereof.

20. A cylindrical slot antenna, comprising:

a hollow cylindrical body constructed of nonconductive material, said body having an outside surface and opposite first and second ends;

a conductive coating on said outside surface;

a plurality of slots in said coating extending in a helical pattern and each having a relatively narrow end and a relatively wide end, each slot having the narrow end thereof adjacent said first end of said body and progressively increasing in width from said narrow end toward said wide end; and

a feed line for each slot connected with an electric circuit, each feed line having a transverse portion extending across the corresponding slot and a longitudinal portion extending generally along and parallel thereto.

21. An antenna as set forth in claim **20**, wherein said wide end of each slot is spaced from said second end of the body.

* * * * *

US006181286B1

(12) **United States Patent**
Roscoe et al.

(10) **Patent No.:** **US 6,181,286 B1**
(45) **Date of Patent:** **Jan. 30, 2001**

(54) **INTEGRATED SATELLITE/TERRESTRIAL ANTENNA**

(75) Inventors: **David Roscoe**, Dunrobin; **Philippe Lafleur**, Ottawa; **Brian Clarke**, Kanata, all of (CA)

(73) Assignee: **Vistar Telecommunications Inc.**, Ottawa (CA)

(*) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

(21) Appl. No.: **09/358,446**

(22) Filed: **Jul. 22, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/093,675, filed on Jul. 22, 1998.

(51) **Int. Cl.**7 .... **H01Q 21/00**
(52) **U.S. Cl.** **343/725**; 343/895; 343/702
(58) **Field of Search** 343/895, 725, 343/729, 702, 856, 857

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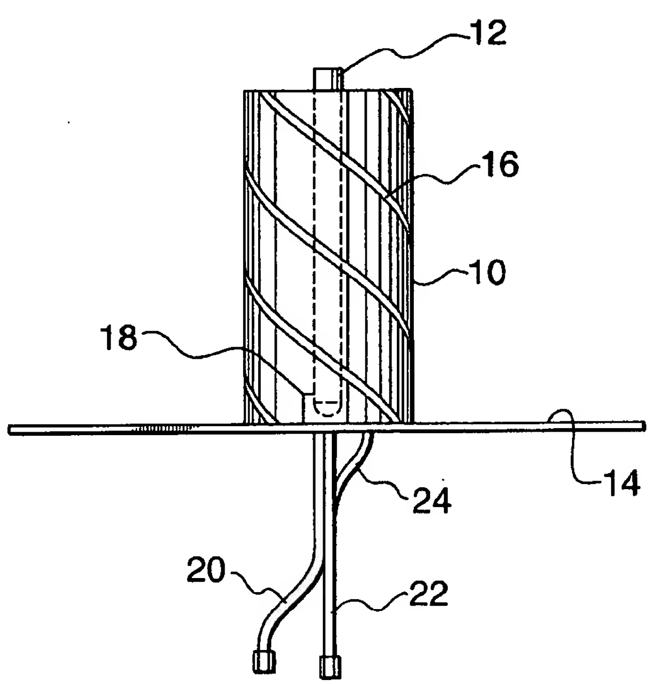
(57) **ABSTRACT**

An integrated dual-mode antenna including a quadrifilar antenna and a collocated monopole antenna. The integrated antenna is compact and unencumbered by signal blockage or isolation problems.

13 Claims, 4 Drawing Sheets



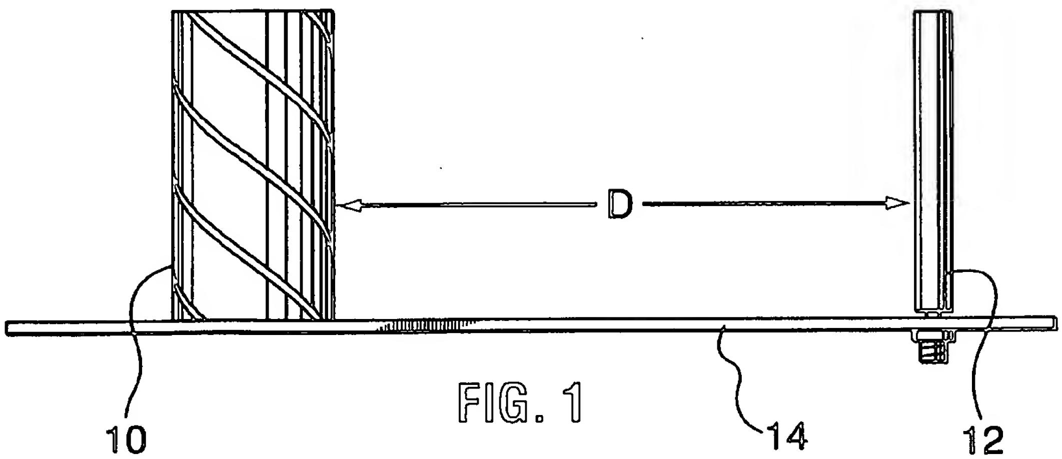


FIG. 1

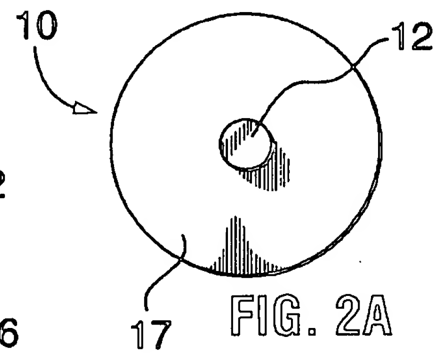


FIG. 2A

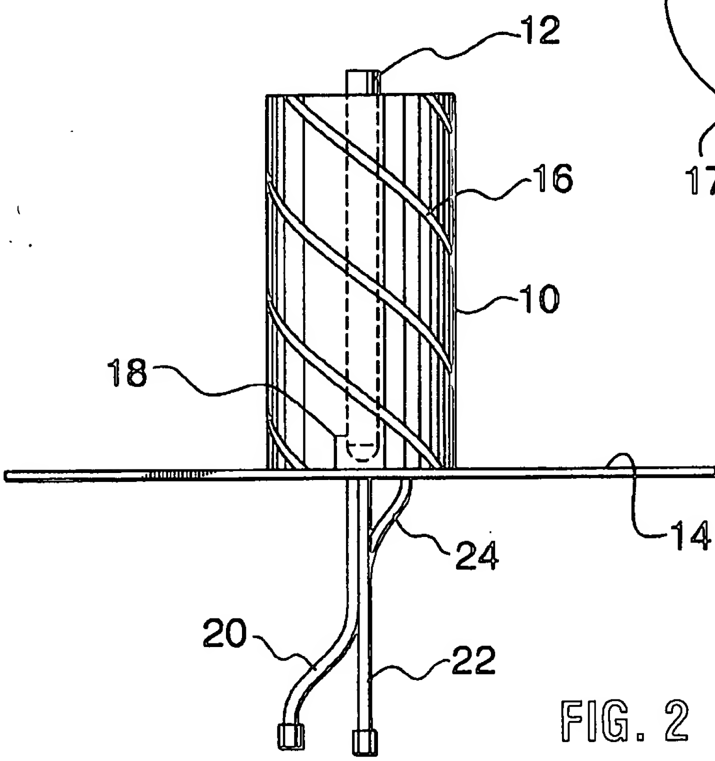
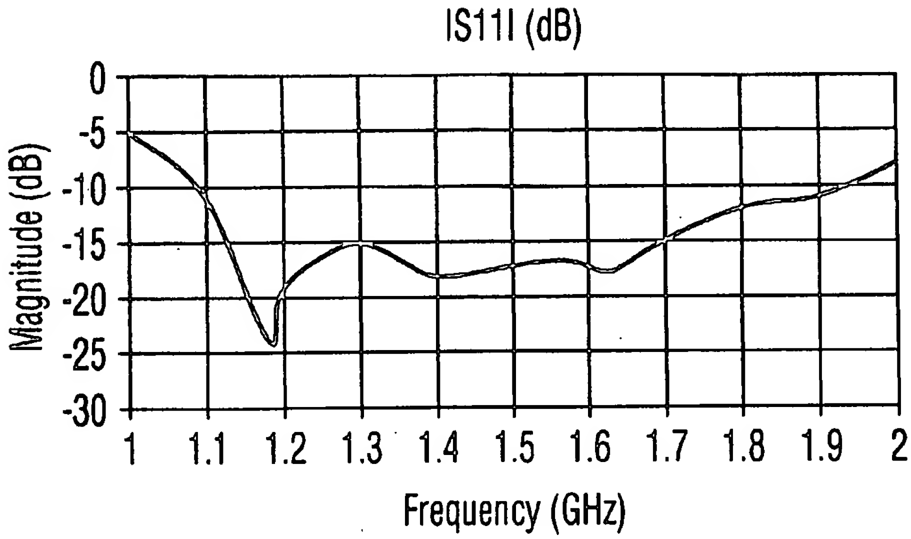
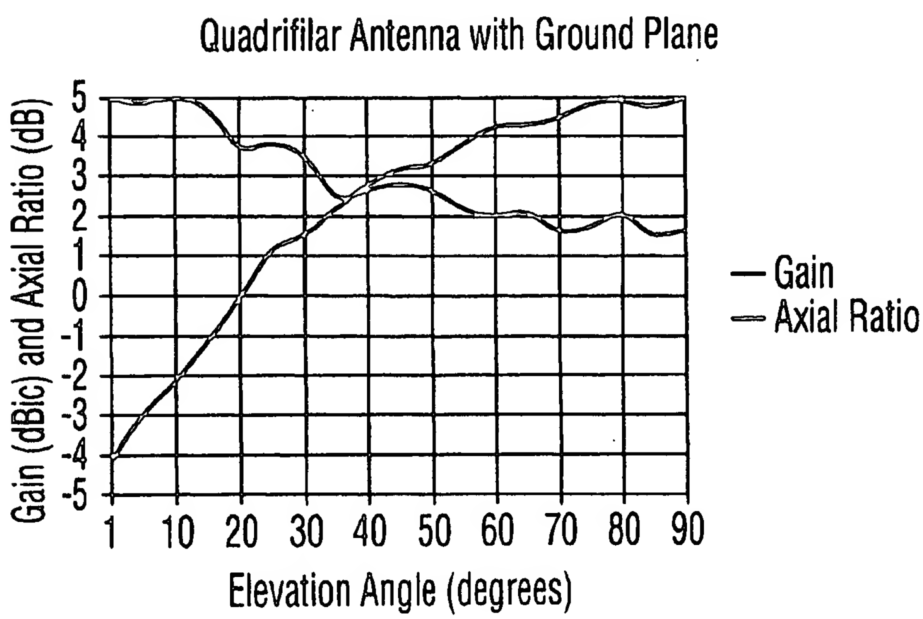


FIG. 2



|S11| (dB)
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Frequency (GHz)

FIG. 3



Quadrifilar Antenna with Ground Plane
Gain (dBic) and Axial Ratio (dB)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1
10
20
30
40
50
60
70
80
90
Elevation Angle (degrees)
Gain
Axial Ratio

FIG. 4

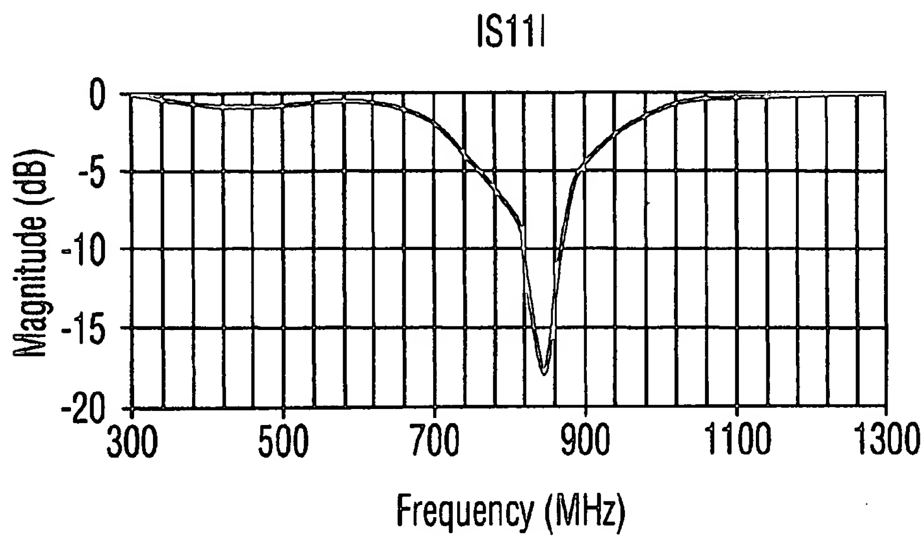

|S11|
Magnitude (dB)
0
-5
-10
-15
-20
300
500
700
900
1100
1300
Frequency (MHz)

FIG. 5

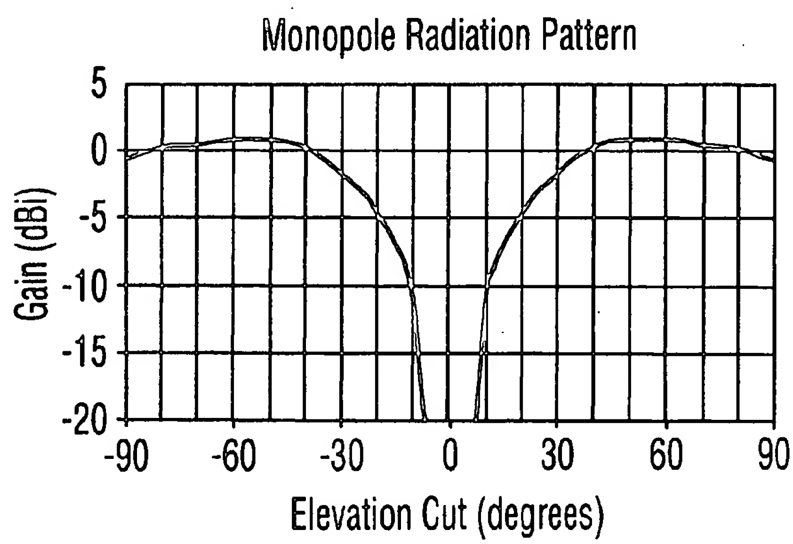

Monopole Radiation Pattern
Gain (dBi)
5
0
-5
-10
-15
-20
-90
-60
-30
0
30
60
90
Elevation Cut (degrees)

FIG. 6

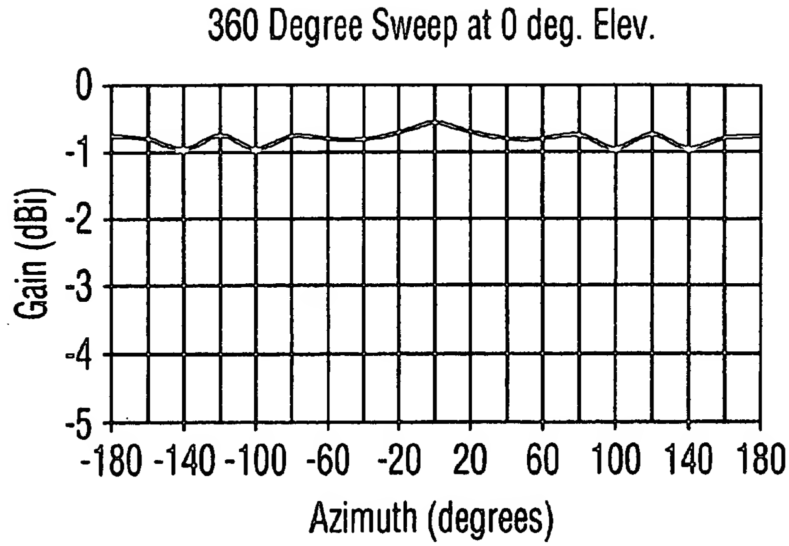

360 Degree Sweep at 0 deg. Elev.
Gain (dBi)
0
-1
-2
-3
-4
-5
-180 -140 -100 -60 -20 20 60 100 140 180
Azimuth (degrees)

FIG. 7

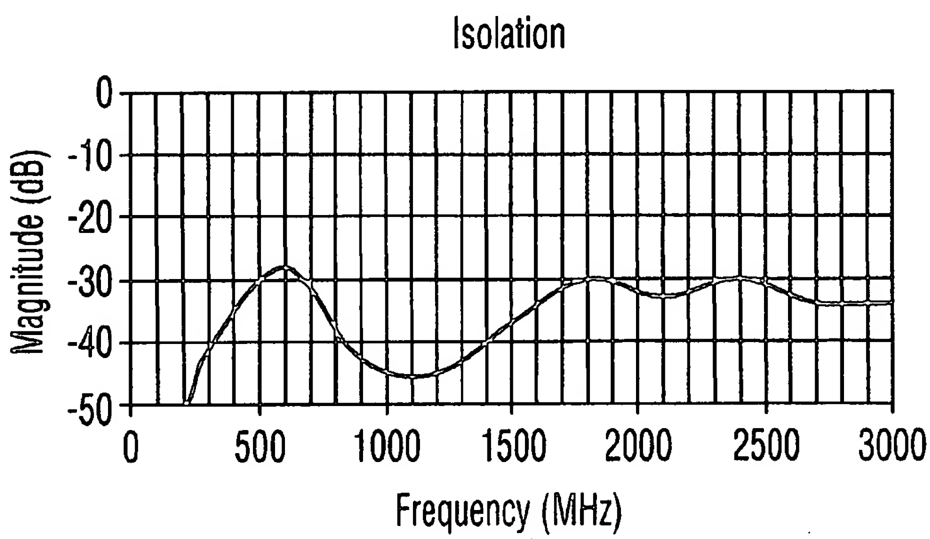

Isolation
Magnitude (dB)
0
-10
-20
-30
-40
-50
0 500 1000 1500 2000 2500 3000
Frequency (MHz)

FIG. 8

INTEGRATED SATELLITE/TERRESTRIAL ANTENNA

This appln claims the benefit of U.S. Provisional No. 60/093,675 filed Jul. 22, 1998.

FIELD OF THE INVENTION

The present invention relates to an integrated antenna and more particularly, the present invention relates to a dual mode antenna system.

BACKGROUND OF THE INVENTION

In the prior art, satellite antennae, terrestrial antennae and integrations of these two have been proposed. Referring initially to the satellite antennae prior art, the quadrifilar helix has been known for several decades. This antenna includes four helical windings fed in phase quadrature. This arrangement provided several characteristics particularly well suited to satellite communications including a hemispherical omnidirectional radiation pattern with excellent circular polarization throughout the radiation pattern as well as compactness and structural simplicity.

For mobile terrestrial communications, the same omnidirectional requirement exists, but the radiation pattern need only to be omnidirectional at the horizon due to the constraints of terrestrial communications on the position of the user relative to base stations. The most common arrangement in the art is the monopole antenna comprising a simple wire above a ground plane.

More contemporary designs of antennae have included dual mode systems. These systems accommodate satellite and terrestrial antennae. These systems present significant design problems particularly with respect to isolation between the two antennae, signal blockage minimization and compactness.

The prior art systems attempted to alleviate the design difficulties by simply placing a satellite antenna and a terrestrial antenna a minimum distance apart such that isolation and blockage requirements were met. Although a generally useful concept, in order to achieve the most desirable performance, a significant separation between the antennae was required. This did not solve the problem of compactness and, in fact, compromised the compactness requirement.

In U.S. Pat. No. 5,600,341, issued Feb. 4, 1997, to Thill et al., there is provided a dual function antenna structure for transceiving in first and second modes.

The apparatus taught in this U.S. patent is a dual frequency single antenna as opposed to a dual mode dual antenna. Accordingly, in the Thill et al. disclosure, there is no teaching with respect to a co-location of two discrete antennae and accordingly, there is no recognition or discussion of the problems encountered when one attempts to co-locate two antennae. The structure provides two feed points for two fields but remains a dual frequency single antenna. This arrangement does not address whatsoever any of the complications inherent in co-location of two antennae such as caging of the signal from antenna to block communication of the co-located antenna.

Further prior art related to the present invention is set forth in U.S. Pat. No. 4,959,657, issued to Mochizuki, issued Sep. 25, 1990. This reference teaches an omnidirectional antenna having a reflector. There is no provision in this reference for the isolation of a monopole antenna with a quadrifilar antenna and accordingly, this reference simply teaches a variation on what is already known in this art.

Moore et al., in U.S. Pat. No. 5,657,792, issued Jul. 22, 1997, discloses a combination GPS and VHF antenna. The combination antenna provides a volute or quadrifilar antenna together with a monopole. Although the elements are provided, there is no co-location between the two antennae which, of course, does not contribute to the compactness of the antenna. By simply providing the combination of the two known antennae in spaced relation, interference problems are not in issue. From a review of the disclosure, it is clear that the Moore et al. reference fails to recognize the value of having a co-located antenna system.

The present invention completely overcomes the limitations in the known art and provides a dual mode antenna system having outstanding performance in a compact system.

SUMMARY OF THE INVENTION

One object of the present invention is to provide an improved dual mode antenna system.

A further object of the present invention is to provide an integrated antenna, comprising:

a quadrifilar antenna; and

a monopole antenna positioned within the quadrifilar antenna and independent of said quadrifilar antenna.

Advantageously, the isolation difficulties inherent with prior art arrangements do not present any concerns in the instant system. In view of the fact that the monopole antenna has a field null in its center, interference or blockage of the monopole signal does not occur, thus allowing the antennae to function as if completely isolated. This feature facilitates collocation of the antennae without any loss in performance.

Another object of the present invention is to provide a method of forming a dual mode integrated antenna, comprising the steps of:

providing a quadrifilar antenna for transceiving circularly polarized fields;

providing a monopole antenna for transceiving linearly polarized fields;

co-locating the monopole antenna within the quadrifilar antenna and independent of the quadrifilar antenna; and

phase coupling the monopole antenna to the quadrifilar antenna.

Having thus described the invention, reference will now be made to the accompanying drawings illustrating preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a dual mode antenna according to the prior art;

FIG. 2 is an elevational view of the antenna in accordance with one embodiment of the present invention;

FIG. 2A is a cross-section of FIG. 2;

FIG. 3 is a graphical illustration of the return loss of the quadrifilar helix;

FIG. 4 is a graphical illustration of the radiation performance of the quadrifilar;

FIG. 5 is a graphical illustration of the return loss of the monopole;

FIG. 6 is a graphical illustration of the elevation cut of the monopole;

FIG. 7 is a graphical illustration of the azimuth sweep of the monopole; and

FIG. 8 is a graphical illustration of the frequency isolation between the two antenna ports.

Similar numerals in the figures denote similar elements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, FIG. 1 illustrates a conventional dual mode antenna system having a cylindrical quadrifilar antenna **10** positioned in spaced relation to a monopole antenna **12**. The antennae are mounted on a ground plane **14** and spaced by a distance D for purposes of isolation and signal blockage minimization.

FIG. 2 depicts an example of the antenna system according to one embodiment of the present invention. In the embodiment shown, the monopole antenna **12** is positioned centrally (coaxially) of the quadrifilar antenna **10**. A capacitor and grounding tab, globally denoted by numeral **18**, are provided. A connection **20** for the quadrifilar antenna is provided for connection with an external source (not shown). A similar connection **22** is provided for the monopole antenna **12**. A brace **24** may be positioned beneath the ground plane **14** for bracing the system. The cylindrical quadrifilar does not demonstrate a field null in its center. The field pattern of the quadrifilar is formed by its windings **16**. As mentioned herein previously, this significantly reduces the effect on performance with the presence of the monopole antenna **12**. In the event that the frequency plan of the dual mode system is such that the satellite communications frequency is approximately an even multiple of the terrestrial communications frequency, the monopole antenna **12** presents a high impedance further improving the isolation between the two antennae **10** and **12**.

In FIG. **2**A, a cross-section of the antenna is shown in which a rigid foam material **17** is disposed between the quadrifilar antenna on its interior surface and the monopole antenna **12**. As illustrated, the monopole antenna **12** is completely surrounded by the material **17**. In instances where rigidity to the overall antenna unit is not required, then the rigid foam may be readily replaced with semi or non-rigid foam material. In terms of the material for the foam, suitable examples include polyurethane foam, polystyrene, polyvinyl chloride foam, inter alia. With respect to the quadrifilar antenna, as illustrated in FIG. **2**, the antenna includes four windings, which windings present a 45° angle relative to the monopole. It has been found that a 45° disposition provides the most effective results, however, for winding dispositions in the range of 36° to 48°, adequate results are obtainable. The windings of the quadrifilar are mounted to a polymeric cylinder as illustrated in FIG. 2 and 2A, with the polymer being selected from any of the suitable polymers, examples of which include Kapton™, Mylar™, etc.

As is known, the quadrifilar antenna windings **16** can interfere or otherwise block a radiated pattern from the monopole antenna **12** to free space. The present invention has advantages in that this "caging" effect can be minimized. This is achieved by selectively positioning the windings **16** of the quadrifilar antenna **10**. It has been found that this is an important feature in that if the angle of the windings is too steep, caging of the monopole antenna **12** will occur. Complications arise in the form of radiation pattern degradation as well as input impedance matching complications. If the pitch of the windings **16** is not steep enough, windings **16** become very close to each other and this results in the formation of an electrical wall which blocks radiation from the lower portion of the monopole antenna **12**. It has been found that a winding pitch degree comprising 45° yielded outstanding results.

Due to coupling from the monopole antenna **12** to the windings **16** of the quadrifilar antenna **10** being in phase, the nature of the quadrature feed network if the quadrifilar antenna leads to phase cancellation of the coupled energy. This contributes to high isolation at the terrestrial operating frequency.

In the figures, the design frequencies were as follows:

Satellite RX:1525–1575.42 MHz

Satellite TX:1610–1660.5 MHz

Terrestrial RX:806–825 MHz

Terrestrial TX:851–870 MHz

FIGS. **3** through **8** demonstrate performance results for the present invention. These results were generated using the windings of the quadrifilar antenna at an angle of 45° as indicated herein.

Although embodiments of the invention have been described above, it is not limited thereto and it will be apparent to those skilled in the art that numerous modifications form part of the present invention insofar as they do not depart from the spirit, nature and scope of the claimed and described invention.

We claim:

1. An integrated dual mode antenna, comprising:

a quadrifilar antenna having a plurality of spaced apart windings and a feed connection for connection with a first feed; and

a monopole antenna positioned within said quadrifilar antenna and independent of said quadrifilar antenna, said monopole antenna having a feed connection for connection with a second feed different from said first feed, said windings of said quadrifilar antenna being at an angle of between 36° to 48° relative to said monopole antenna.

2. The integrated antenna as set forth in claim **1**, wherein said quadrifilar antenna includes four windings.

3. The integrated antenna as set forth in claim **1**, wherein coupling from said monopole antenna to said quadrifilar antenna is in phase.

4. The integrated antenna as set forth in claim **1**, wherein said windings are at a 45° angle relative to said monopole antenna.

5. The integrated antenna as set forth in claim **1**, wherein said monopole is coaxially positioned within said quadrifilar antenna.

6. The integrated antenna as set forth in claim **1**, wherein said windings of said quadrifilar antenna are mounted to a polymeric cylinder.

7. The integrated antenna as set forth in claim **1**, wherein said quadrifilar antenna transceives circularly polarized fields and said monopole antenna transceives linearly polarized fields independently of said quadrifilar antenna.

8. The integrated antenna as set forth in claim **1**, wherein said plurality of windings are equidistant.

9. The integrated antenna as set forth in claim **1**, wherein a foamed polymer is positioned between said quadrifilar antenna and said monopole antenna.

10. The integrated antenna as set forth in claim **9**, wherein said foamed polymer surrounds said monopole antenna.

11. A method of forming a dual mode integrated antenna, comprising the steps of:

providing a quadrifilar antenna for transceiving circularly polarized fields;

providing a monopole antenna for transceiving linearly polarized fields;

providing a separate feed connection for each of said guadrifilar antenna and said monopole antenna;

co-locating said monopole antenna within said quadrifilar antenna and independent of said quadrifilar antenna; and

phase coupling said monopole antenna to said quadrifilar antenna.

12. The method as set forth in claim 11, further including the step of positioning a rigid polymeric foam material between said monopole antenna and said quadrifilar antenna.

13. The method as set forth in claim 12, wherein said polymeric foam completely surrounds said monopole antenna.

* * * * *

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Leisten et al.

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(45) Date of Patent: *Feb. 6, 2001

(54) DIELECTRIC-LOADED ANTENNA

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(73) Assignee: Symmetricom, Inc., San Jose, CA (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

(21) Appl. No.: 08/889,998

(22) Filed: Jul. 10, 1997

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May 9, 1997 (GB) 9709518

(51) Int. Cl.[7] H01Q 1/36
(52) U.S. Cl. 343/895; 343/821; 343/859
(58) Field of Search .... 343/895, 700 MS, 343/702, 752

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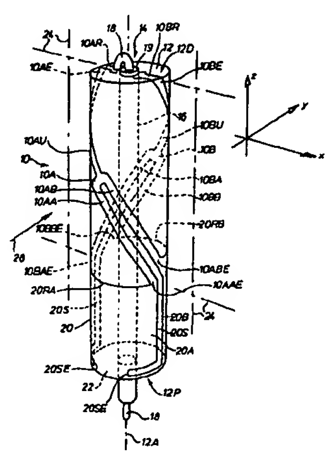
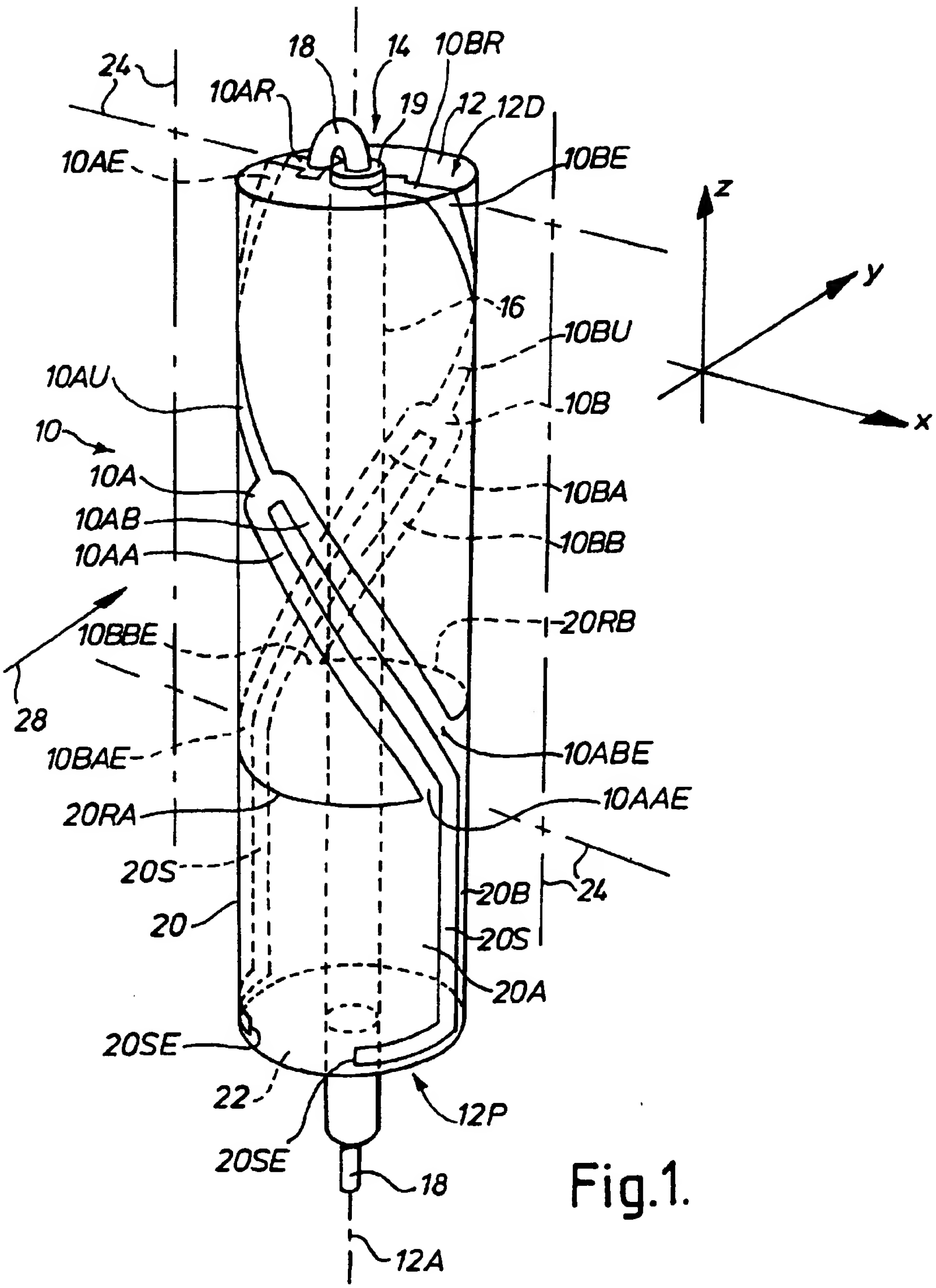
(57) ABSTRACT

A dielectric-loaded loop antenna for operation at frequencies above 200 MHz has an elongate cylindrical core with a relative dielectric constant greater than 5, a pair of co-extensive helical antenna elements, a coaxial feeder structure extending through the core from a proximal end to a distal end where it is coupled to the antenna elements, and a balun formed on the core cylindrical surface and connected to the feeder structure at the proximal end of the core. Each helical antenna element is bifurcated at an intermediate position so that proximally, it is formed of two generally parallel branches each of which is coupled to a respective linking path around the core to meet a corresponding branch of the other elongate element therefore forming a conductive loop between the two conductors of the feeder structure. The two conductive loops have different electrical lengths as a result of, for example, the branches being of different lengths. In a preferred embodiment, the linking paths around the core are formed by the rim of a split conductive sleeve constituting the balun. The sleeve is formed in two parts separated by a pair of longitudinally extending diametrically opposed quarter wave slits each of which extends from the space between the branches of a respective helical antenna element to a short circuited end adjacent the proximal end of the core.

42 Claims, 5 Drawing Sheets

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10BAE
10ABE
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18
12A

Fig.1.

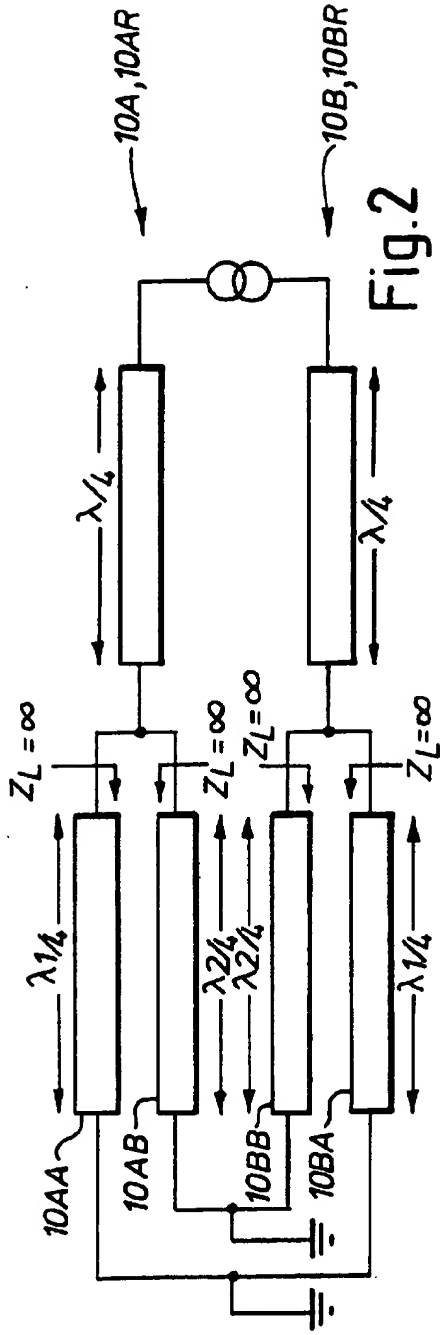


Fig.2

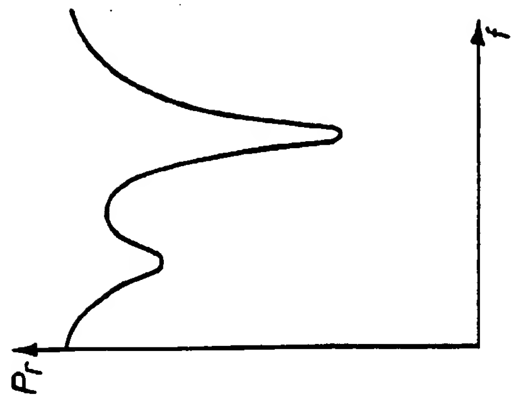


Fig.3C

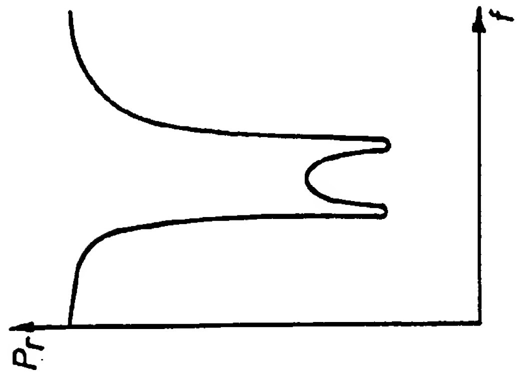


Fig.3B

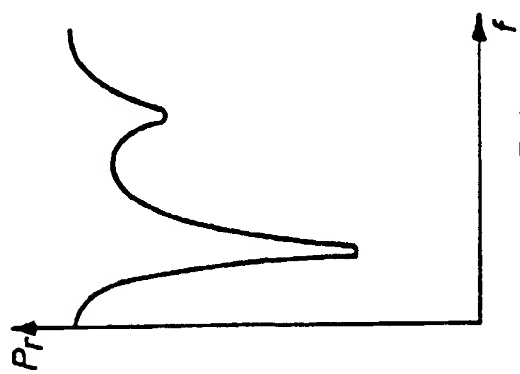


Fig.3A

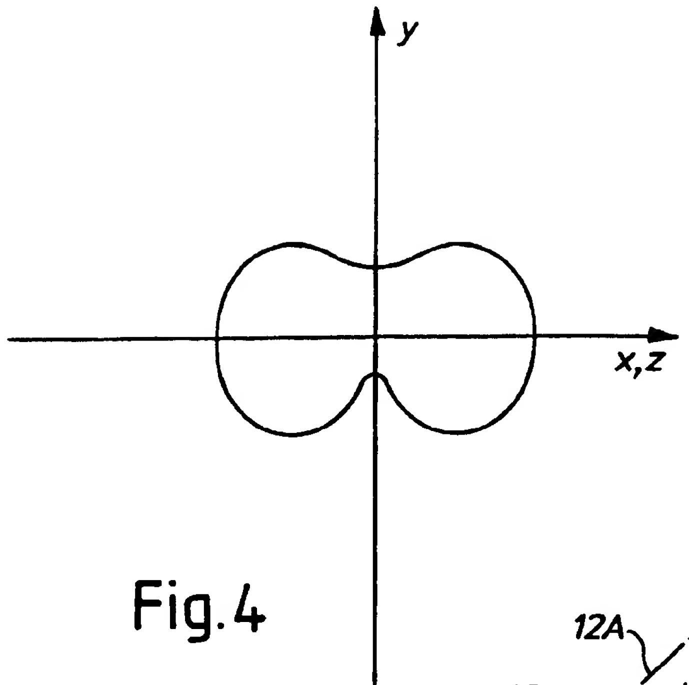


Fig.4

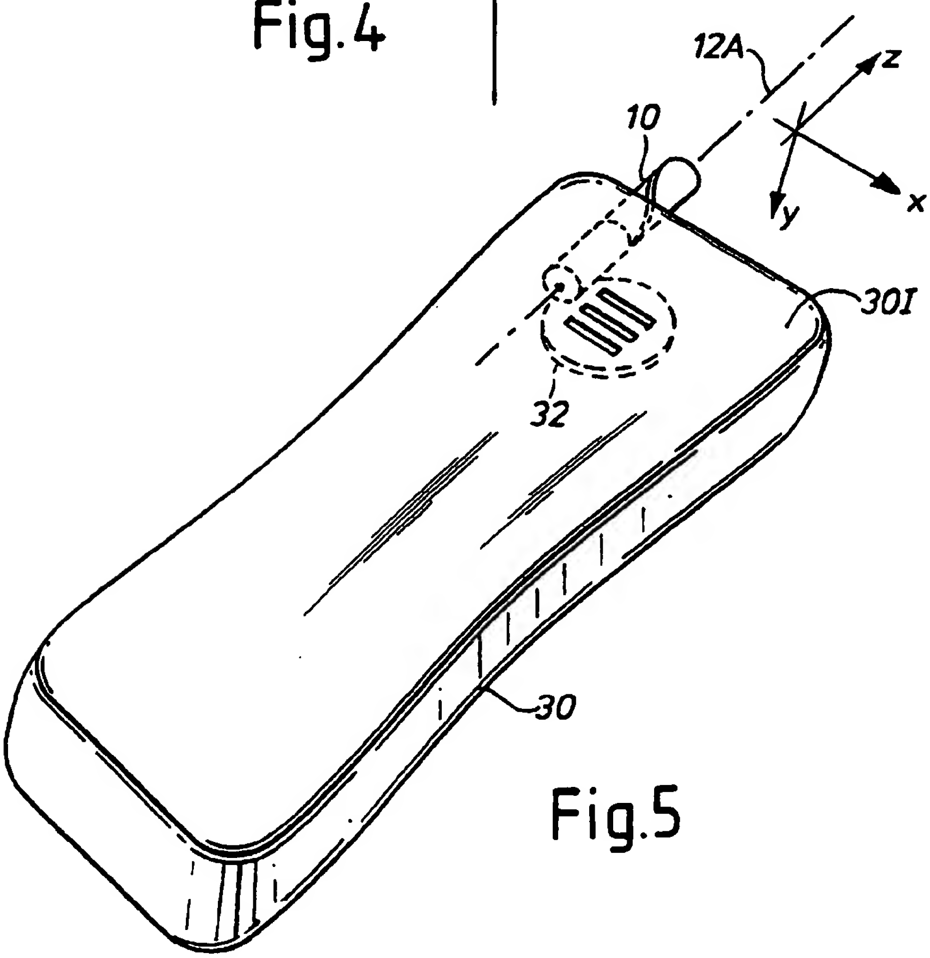
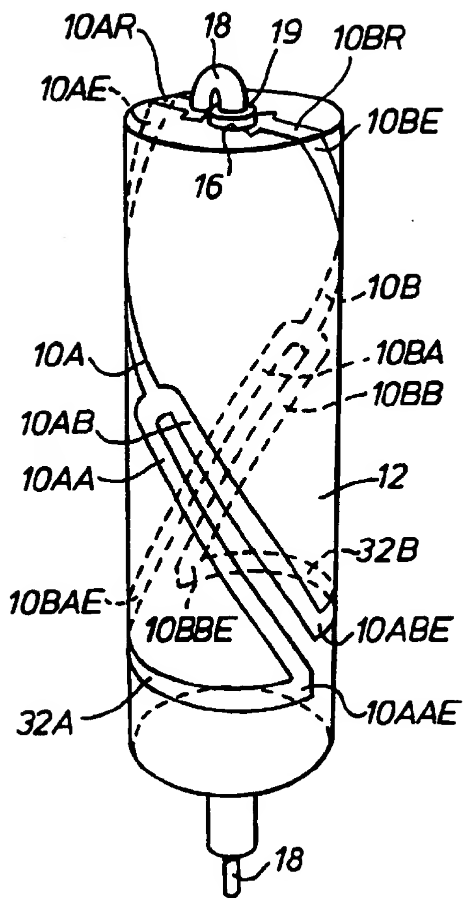


Fig.5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18
19
10BR
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10BE
16
10B
10A
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10BB
10AB
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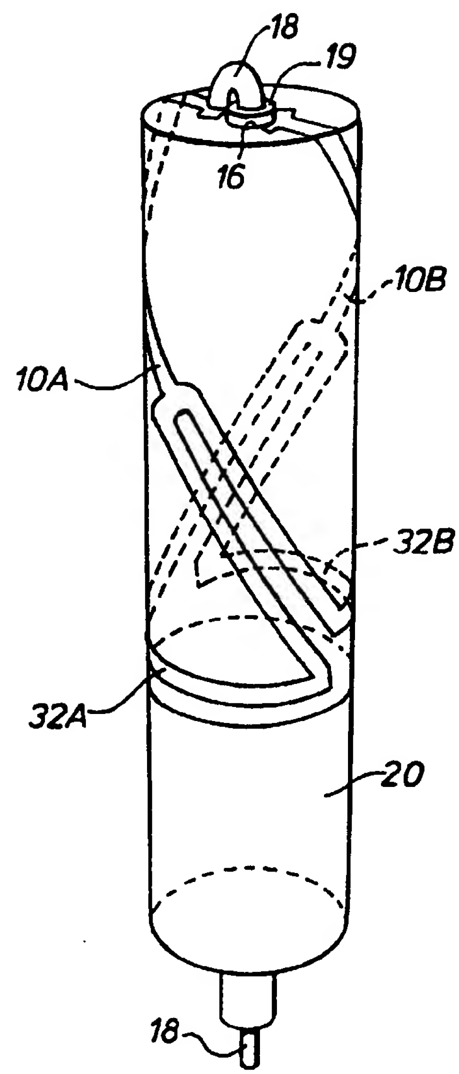
10BBE
10ABE
32A
10AAE
18

Fig.6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19
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10A
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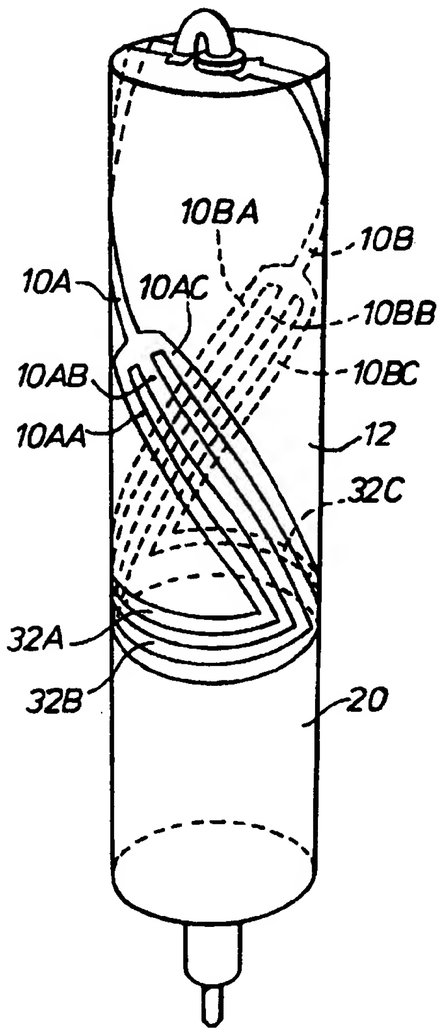
32A
20
18

Fig.7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10BB
10AB
10BC
10AA
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32C
32A
32B
20

Fig.8

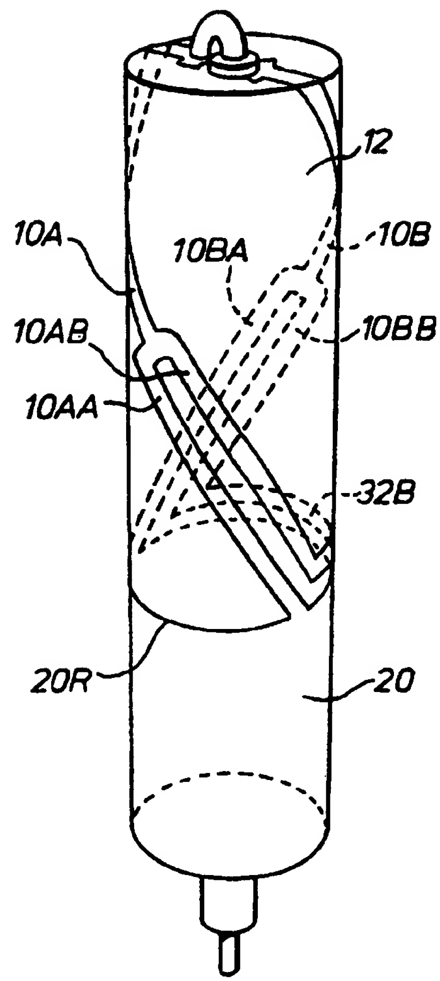
12
10A
10BA
10B
10AB
10BB
10AA
32B
20R
20

Fig.9

DIELECTRIC-LOADED ANTENNA

FIELD OF THE INVENTION

This invention relates to dielectric-loaded antenna for operation at frequencies in excess of 200 MHz, and having a three-dimensional antenna element structure on or adjacent the surface of an elongate dielectric core which is formed of a solid material having a relative dielectric constant greater than 5.

BACKGROUND OF THE INVENTION

An antenna as described above is known from published UK Patent Application No. GB 2292638A which discloses a quadrifilar antenna having an antenna element structure with four helical antenna elements formed as metallic conductor tracks on the cylindrical outer surface of a cylindrical ceramic core. The core has an axial passage with an inner metallic lining and the passage houses an axial feeder conductor, the inner conductor and the lining forming a coaxial feeder structure for connecting a feed line to the helical antenna elements via radial conductors formed on the end of the core opposite the feed line. The other ends of the antenna elements are connected to a common virtual ground conductor in the form of a plated sleeve surrounding a proximal end portion of the core and connected to the outer conductor of the coaxial feeder formed by the lining of the axial passage. The sleeve, in conjunction with the feeder structure forms a trap, isolating the helical elements from ground, yet providing conductive paths around its rim interconnecting the helical elements. This antenna is intended primarily as an omnidirectional antenna for receiving circularly polarised signals from sources which may be directly above the antenna, i.e. on its axis, or at smaller angles of elevation down to a few degrees above a plane perpendicular to the axis. It follows that this antenna is particularly suitable for receiving signals from global positioning system (GPS) satellites. Since the antenna is also capable of receiving vertically or horizontally polarised signals, it may be used in other radiocommunication apparatus such as handheld cordless or mobile telephones.

A dielectric-loaded antenna which is particularly suited to portable telephone use is a bifilar helical loop antenna in which two diametrically opposed half turn helical elements form, in conjunction with a conductive sleeve as described above, a twisted loop yielding a radiation pattern which is omnidirectional with the exception of two opposing nulls centred on an axis perpendicular to the plane formed by the four ends of the two helical elements. This antenna is disclosed in our co-pending U.S. patent application Ser. No. 08/664,104 the contents of which form part of the disclosure of the present application by reference. When this loop antenna is appropriately mounted in a mobile telephone handset, the presence of the nulls reduces the level of radiation directed into the user's head during signal transmission. While the antenna gain is superior to many prior mobile telephone handset antennas, it is significantly less than the maximum value above and below a central resonant frequency. It is an object of this invention to provide an antenna of relatively wide bandwidth or capable of operating in two frequency bands.

SUMMARY OF THE INVENTION

According to a first aspect of this invention, there is provided a dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising an elongate dielectric core formed of a solid material having a relative dielectric constant greater than 5 and, on or adjacent the surface of the core, a three-dimensional antenna element structure including at least a pair of laterally opposed elongate antenna elements which extend between longitudinally spaced-apart positions on the core, and linking conductors extending around the core to interconnect the said elements of the pair, the elongate elements having respective first ends coupled to a feed connection and second ends coupled to the linking conductors, wherein the said elongate elements and the linking conductors together form at least two looped conductive paths each extending from the feed connection to a location spaced lengthwise of the core from the feed connection, then around the core, and back to the feed connection, the electrical length of one of the two paths being greater than that of the other path at an operating frequency of the antenna. Since the looped conductive paths have different electrical lengths, their resonant frequencies are different and can be selected so as to coincide, for example, with the centre frequencies of the transmit and receive bands of a mobile telephone system.

The linking conductors may be formed by a quarter wave balun on the outer surface of the core adjacent the end opposite to the feed connection, the latter being provided by a feeder structure extending longitudinally through the core. In one preferred embodiment, the linking conductors are formed by mutually isolated parts of a balun sleeve so that each of the two looped conductive paths includes the rim of a respective sleeve part. The sleeve parts are isolated from each other by longitudinally extending slits in the conductive material forming the sleeve, the electrical length of each slit from a respective short-circuited end to the relevant sleeve rim being at least approximately equal to a quarter wavelength at the operating frequency so that isolation between the two sleeve parts is provided at their junctions with the elongate antenna elements.

Alternatively, each linking conductor may be formed by a conductive strip extending around a respective side of the core from one elongate antenna element to another. In another alternative, one linking conductor may be formed in this way, and the other may be formed by the rim of a quarter wave balun sleeve, with or without the slits described above. The advantage of incorporating a balun sleeve is that the antenna may then operate in a balanced mode from a single-ended feed coupled to the feeder structure.

Advantageously, the antenna element structure has a single pair of laterally opposed elongate antenna elements each of which is forked so as to have a divided portion which extends from a location between the first and second ends of the element as far as a respective one of the linking conductors. The difference in electrical length between the two looped conductive paths may be achieved by forming one or both of the divided portions as branches of different electrical lengths. Each branch may then be connected to respective linking conductors extending around opposite sides of the core which, at least in the region of the elongate elements are isolated from each other. It will be appreciated that the difference in path lengths may be achieved not only by making the branches of different lengths, but by forming the linking conductors differently on opposite sides of the core.

Particularly satisfactory operation can be achieved by arranging for the electrical length of each branch to be approximately 90° (or $(2n+1)\lambda/4$ where $n=0, 1, 2 \ldots$) at the resonant frequency of its respective conductive path, λ being the corresponding wavelength. The linking conductors represent a location of low impedance at the operating frequency, and each 90° length acts as a current-to-voltage transformer so that the impedance at the fork of each forked

element is relatively high. Accordingly, at the resonant frequency of one of the conductive paths, excitation occurs in that path simultaneously with isolation from the other path or paths. It follows that two or more distinct resonances can be achieved at different frequencies due to the fact that each branch loads the conductive path of the other only minimally when the other is at resonance. In effect, two or more mutually isolated low impedance paths are formed around the core.

In the preferred antenna in accordance with the invention, the advantageous low impedance connection point for the antenna elements at their junction with the linking conductor or conductors is provided by annular linking conductors in the form of a cylindrical split conductive sleeve which operates in conjunction with a feeder structure extending longitudinally through the core to form an isolating trap which causes currents circulating around the looped conductive paths to be confined to the rim of the sleeve. By connecting the proximal end of the sleeve to the feeder structure and arranging for the longitudinal electrical length of the sleeve to be at least approximately n×90° within the operating frequency band of the antenna (where n is an odd number), the sleeve provides a virtual ground for the elongate antenna elements. The sleeve is split in the sense that longitudinally extending slits are formed as breaks in the conductive material of the sleeve. Thus, in the case of each elongate antenna element having branches as described above which are connected to the rim of the sleeve, there are two slits each of which extends from the space between the branches of a respective one of the elongate antenna elements to a respective short circuited end thereby forming two part-cylindrical sleeve parts. Since the slits each have an electrical length of about a quarter wavelength (λ/4) in the operating frequency band, the zero impedance of the short-circuited end is transformed to a high impedance between the sleeve parts at their junctions with the branches of the elongate antenna elements.

To accommodate the preferred λ/4 electrical length for each slit, each may be L-shaped, having a first part which runs longitudinally and a second part adjacent the short circuited end which runs perpendicularly to the longitudinal part. By arranging for one of the second end parts to be directed in one direction around the core and the other second part to be directed in the opposite direction around the core, the electrical length of one of the sleeve parts can be increased with respect to the other (by virtue of a pinching of the longitudinal conductive path). The significance of this becomes apparent when the rim of one sleeve part is at a different longitudinal location from the rim of the other sleeve part, in that if the pinching is arranged in the shorter of the sleeve parts, its electrical length may be increased so that the frequency at which the balun action occurs most effectively is brought nearer to the resonant frequency of the longer of the two looped conductive paths. Thus, with the ends of the elongate antenna elements lying generally in a common plane, the rim of the complete sleeve is effectively stepped insofar as the connection it provides around one side of the antenna is at a different longitudinal position on the core from the connection it provides around the opposite side. This means that if each forked antenna element has two branches, one shorter than the other, the shorter ones may be connected to that portion of the sleeve rim which is nearer the distal end of the core while the other, longer branches are connected to that part of the rim which is further from the distal end thereby creating conductive loops at different lengths and with different resonant frequencies. The branched portions of each element advantageously run parallel and close to each other, terminating on the sleeve rim at the bottom and top of the respective step in the rim, i.e. at the high impedance ends of the slit.

Extension of the antenna bandwidth and a reduction in physical length may be achieved, in the case of a cylindrical rod-shaped core by forming each elongate antenna element as a half-turn helix. Preferably, the helix is forked at a position approximately midway between the end of the rod and the linking conductor.

According to another aspect of the invention, a dielectric-loaded loop antenna for operation at frequencies above 500 MHz comprises an elongate cylindrical core having a relative dielectric constant greater than 5, and an antenna element structure on the core outer surface comprising a pair of diametrically opposed elongate antenna elements and annularly arranged linking conductors. The elongate elements extend from a feed connection at one end of the core to the linking conductors, with the ends of the elongate elements preferably lying substantially in a common plane containing the core axis insofar as the angular differences between the lines formed by radii joining the ends of the elongate elements to the core axis are no more than 20°. To achieve resonances at spaced apart frequencies, the elongate elements are each bifurcated to define two looped conductive paths of different electrical lengths, each coupled to the feed connection.

The invention also includes, according to yet a further aspect, a handheld radio communication unit having a radio transceiver, an integral earphone for directing sound energy from an inner face of the unit which, in use, is placed against the user's ear, and an antenna as described above. The antenna is mounted such that the common plane lies generally parallel to the inner face of the unit so that a null in the radiation pattern of the antenna exists in the direction of the user's head.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below by way of example with reference to the drawings in which:

FIG. **1** is a perspective view of an antenna in accordance with the invention;

FIG. **2** is an equivalent circuit diagram of part of the antenna of FIG. **1**;

FIGS. **3A**, **3B** and **3C** are graphs showing reflected power as a function of frequency;

FIG. **4** is a diagram illustrating the radiation pattern of the antenna of FIG. **1**;

FIG. **5** is a perspective view of a telephone handset, incorporating an antenna in accordance with the invention;

FIG. **6** is a perspective view of a first alternative antenna in accordance with the invention;

FIG. **7** is a perspective view of a second alternative antenna in accordance with the invention;

FIG. **8** is a perspective view of a third alternative antenna in accordance with the invention; and

FIG. **9** is a perspective view of a fourth alternative antenna in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, a preferred antenna **10** in accordance with the invention has an antenna element structure with two longitudinally extending metallic antenna elements **10A**, **10B** on the cylindrical outer surface of a ceramic core **12**.

The core 12 has an axial passage 14 with an inner metallic lining 16, and the passage houses an axial inner feeder conductor 18 surrounded by a dielectric insulating sheath 19. The inner conductor 18 and the lining 16 in this case form a feeder structure for coupling a feed line to the antenna elements 10A, 10B at a feed position on the distal end face 12D of the core. The antenna element structure also includes corresponding radial antenna elements 10AR, 10BR formed as metallic conductors on the distal end face 12D connecting diametrically opposed ends 10AE, 10BE of the respective longitudinally extending elements 10A, 10B to the feeder structure.

In this embodiment, the longitudinally extending elements 10A, 10B are of equal average length, each being in the form of a helix executing a half turn around the axis 12A of the core 12, each helix laterally opposing the other and being longitudinally co-extensive. It is also possible for each helix to execute multiple half turns, e.g. a full turn or 1½ turns. The antenna elements 10A, 10B are connected respectively to the inner conductor 18 and outer lining 16 of the feeder structure by their respective radial elements 10AR, 10BR.

Each of the longitudinally extending elements 10A, 10B has a proximal divided portion formed by respective pairs of parallel substantially quarter wave branches 10AA, 10AB and 10BA, 10BB. These branches extend in generally the same direction as the undivided portion 10AU, 10BU, of each element 10A, 10B, the junction between undivided and divided portions being, in this embodiment, approximately midway between the distal and proximal ends of elements 10A, 10B. To form complete conductive loops, each antenna element branch 10AA, 10AB, 10BA, 10BB is connected to the rim (20RA, 20RB) of a common virtual ground conductor 20 in the form of a conductive sleeve surrounding a proximal end portion of the core 12. This sleeve 20 is in turn connected to the lining 16 of the axial passage 14 by plating 22 on the proximal end face 12P of the core 12. Thus each conductive loop formed by the helical elements 10A, 10B (including the respective branches), the radial elements 10AR, 10BR, and the rim of the respective portion 20RA, 20RB of the sleeve 20 is fed at the distal end of the core by a feeder structure which extends through the core from the proximal end, and lies between the antenna elements 10A, 10B. The antenna consequently has an end-fed bifilar helical structure.

Over at least its upper or distal portion, the sleeve 20 is split into two opposed parts 20A, 20B each subtending an angle approaching 180° at the core axis 12A, and separated from each other by longitudinal slits 20S which are breaks in the conductive material of the sleeve 20 extending from the spaces between the proximal ends 10AAE, 10ABE, 10BAE, 10BBE of the antenna element branches to short-circuited ends 20SE.

In this embodiment each of the slits 20S has a longitudinal portion parallel to the core axis and a tail portion which extends around the core, the two portions forming an "L". The lower tail portions are directed in opposite directions towards each other so as to pinch the width of the shorter (20A) of the two sleeve parts 20A, 20B.

At any given transverse cross-section through the antenna 10, the antenna elements 10A, 10B are substantially diametrically opposed, and the proximal ends 10AAE, 10ABE, 10BAE, 10BBE of the antenna element branches are also substantially diametrically opposed where they meet the rim of sleeve 20, as are the slits 20S.

It will be noted that the ends 10AE, 10BE, 10AAE, 10ABE, 10BAE, 10BBE of the antenna elements 10A, 10B all lie substantially in a common plane containing the axis 12A of the core 12. The effect of this is explained hereinafter. This common plane is indicated by the chain lines 24 in FIG. 1. The feed connection to the antenna element structure and the feeder structure also lie in the common plane 24.

In this preferred antenna as shown in FIG. 1, the conductive sleeve 20 covers a proximal portion of the antenna core 12, thereby surrounding the feeder structure 16, 18, the material of the core 12 filling the whole of the space between the sleeve 20 and the metallic lining 16 of the axial passage 14. The sleeve 20 forms a split cylinder connected to the lining 16 by the plating 22 of the proximal end face 12P of the core 12, the combination of the sleeve 20 and plating 22 forming a balun so that signals in the transmission line formed by the feeder structure 16, 18 are converted between an unbalanced state at the proximal end of the antenna and a balanced state at an axial position approximately in the plane of the upper edge 20RA, 20RB of the sleeve 20. To achieve this effect, the axial lengths of the sleeve parts 20A, 20B are such that in the presence of an underlying core material of relatively high dielectric constant, the balun has an electrical length of about $\lambda/4$ or 90° in the operating frequency band of the antenna. Since the core material of the antenna has a foreshortening effect, and the annular space surrounding the inner conductor 18 is filled with an insulating dielectric material 19 having a relatively small dielectric constant, the feeder structure distally of the sleeve 20 has a short electric length. As a result, signals at the distal end of the feeder structure 16, 18 are at least approximately balanced.

A further effect of the sleeve 20 is that for signals in the region of the operating frequency of the antenna, the rim parts 20RA, 20RB of the sleeve 20 are effectively isolated from the ground represented by the outer conductor 16 of the feeder structure. This means that currents circulating between the antenna elements 10A, 10B are confined substantially to the rim parts. The sleeve 20 thus acts as an isolating trap to reduce the phase-distorting influence of unbalanced currents in the antenna.

The preferred material for the core 12 of the antenna is a zirconium-titanate-based material. This material has a relative dielectric constant of 36 and is noted also for its dimensional and electrical stability with varying temperature. Dielectric loss is negligible. The core may be produced by extrusion or pressing.

The antenna elements 10A, 10B, 10AR, 10BR are metallic conductor tracks formed on or adjacent the outer cylindrical and distal end surfaces of the core 12, each track being of a width at least as great as its thickness over its operative length. The tracks may be formed by initially plating the surfaces of the core 12 with a metallic layer and then selectively removing the layer to expose the core according to the required pattern. Alternatively, the metallic material may be applied by selective deposition or by printing techniques. In all cases, the formation of the tracks as an integral elements at the outside of a dimensionally stable core leads to an antenna having dimensionally stable antenna elements.

It will be understood from the above that the longitudinally extending antenna elements 10A, 10B, together with the rim portions 20RA, 20RB of the sleeve parts 20A, 20B, form two looped conductive paths in the operating frequency range of the antenna, each looped path being isolated from ground. Thus, a first looped conductive path begins at the feed connection on the distal face 12D of the core and extends via radial conductor 10AR, the upper portion of

element 10A, one of the branches 10AA of the lower portion of element 10A, a first semicircular portion 20RA of the rim of sleeve 20 extending around one side of the core 12, one of the branches 10BA of element 10B, the distal portion of element 10B and, finally, the radial conductor 10BR back to the feeder. The other conductive path also forms a loop beginning at the feeder. In this case, the path follows element 10AR, the distal portion of element 10A, the other branch 10AB of element 10A, the other portion 20RB of the rim of sleeve 20, this time extending around the opposite side of the core 12 from rim portion 20RA, then via the other branch 10BB of antenna element 10B, the distal portion of element 10B and, finally, back to the feeder via radial element 10BR.

These two conductive paths are of different physical and electrical lengths as a result of the branches 10AA, 10BA of the first conductive path being longer than those 10AB, 10BB of the second conductive path, and by virtue of the rim portion 20RA being further from the feed connection at the distal end 12D of the core than the other rim portion 20RB. This difference in height between the two rim portions 20RA and 20RB results in the rim having a stepped profile with the antenna element branches of each element 10A, 10B being joined to the sleeve 20 on opposite sides of the rim steps, as shown in FIG. 1. As a result of the differing lengths of the looped conductive paths, they have different resonant frequencies.

An equivalent circuit diagram representing the antenna element structure of the antenna of FIG. 1 is shown in FIG. 2. The undivided distal portion of each antenna element 10A, 10B, together with the respective radial connections 10AR, 10BR may be represented by a transmission line section of an electrical length which is at least approximately equal to $\lambda/4$ or, more generally, $(2n+1)\lambda/4$ where λ is the centre wavelength of the antenna operating band and $n=0, 1, 2, 3\ldots$ The branches 10AA, 10AB, 10BA, 10BB are represented by similar transmission line sections, i.e. as two pairs of parallel-connected sections, all connected in series between the distal portions of the antenna elements 10A, 10B and the virtual ground represented by the rim portions 20RA, 20RB of the sleeve 20. The branch sections have electrical lengths $\lambda_1/4$ or $\lambda_2/4$ as shown, depending whether they are part of the longer or the shorter looped conductive path, the longer having a resonant frequency corresponding to a wavelength λ_1 and the shorter having a resonant frequency corresponding to a wavelength λ_2.

Since the isolating effect of the sleeve 20 confines currents mainly to the rim portions 20RA, 20RB when the antenna is resonant in a loop mode, they represent locations of current maxima. For signals having a wavelength in the region of λ_1 and λ_2, the quarter wavelength branches 10AA–10BB act as current-to-voltage transformers so that at the point where each antenna element is split there is a voltage maximum and the impedance looking into each branch tends to infinity, as shown in FIG. 2. Consequently, when one conductive loop is in resonance, the impedance looking into the branches of the other loop is high (providing λ_1 and λ_2 are of the same order). This means that the resonance of one loop is not significantly affected by the conductors of the other loop. There is, therefore, a degree of isolation between the two resonant modes embodied in two distinct paths.

The individual antenna elements 10A, 10B, being each split into two parallel conductors passing from the balun connection point (i.e. the sleeve rim) to the points of voltage maxima at intermediate locations along the elements, isolate the two resonant paths (the conductive loops) from each other. This arrangement, as shown in FIG. 2, may be viewed as either a transforming or coupled line system.

The stepped sleeve rim 20RA, 20RB not only creates two differing loop path-lengths around opposite sides of the core such that two resonant frequencies are possible, but also it splits the choke balun represented by the sleeve 20 into two parallel resonant lengths.

It should be noted that each longitudinal slit 20S in the sleeve 20 is arranged to have an electrical length in the region of a quarter wavelength at the centre frequency of the required operating frequency range, and it is for this reason that they are L-shaped in the embodiment of FIG. 1. It will be appreciated that sufficient length can be obtained from other configurations, for example by causing the slits to have a meandered path or by allowing them to extend around the proximal edge of the antenna into the plating 22 on the proximal end face 12P of the core 12. These quarter wave slits 20S have the effect of isolating the upper regions of the two sleeve parts 20A, 20B from each other so as to confine the currents in the longer of the two conductive loops to the rim portion 20RA, and those in the shorter loop to the rim portion 20RB. Isolation is achieved by transformation of the zero impedance of the short circuited ends 20SE to a high impedance between the sleeve parts 20A, 20B at the level of the two rim parts 20RA, 20RB.

Arranging the tail portions of the slits 20S to be directed towards each other as shown in FIG. 1 has the effect of introducing a restriction in the current path between the rim portion 20RA of the shorter (20A) of the two sleeve parts 20A, 20B and the connection of the sleeve to the feeder structure 16 at the proximal end of the core. This restriction increases the longitudinal impedance of sleeve part 20A, in effect by adding an inductance, thereby tending to reduce the frequency at which the balun effect due to that sleeve part 20A is most pronounced. Indeed, this frequency can be made to coincide with the resonant frequency of the looped conductive path which includes the rim of this sleeve part 20A, in this case the longer of the looped conductive paths.

The length of the slits has an effect on the ability of the antenna to operate efficiently at spaced frequencies. Referring to FIGS. 3A, 3B, and 3C, if the slit is too short to promote effective isolation between the upper regions of the two sleeve parts 20A, 20B, a comparatively weak secondary peak is formed at the higher of two resonant frequencies, as shown in FIG. 3A. At an optimum slit length, strong isolation is obtained and constructive combination of the two resonances due to the two conductive loops occurs, as shown in FIG. 3B, from which it will be seen that strong resonances occur at two spaced apart frequencies which, however, are closer together than the two frequencies of resonance shown in FIG. 3A. If the length of the slits is increased further, isolation is less effective and the antenna has a primary resonance at a higher frequency and a weaker, secondary resonance at a lower frequency; the opposite situation to that of FIG. 3A. Depending on the tolerance to which the antenna is manufactured, individual adjustment of each antenna can be provided by initially forming the slits with a comparatively short overall length, and removing the conductive material of the sleeve 20 at the slit ends 20SE according to test results. This can be done by, for instance, grinding, or by laser ablation.

Arranging for the ends 10AE, 10BE, 10AAE, 10ABE, 10BAE, and 10BBE of the antenna elements 10A, 10B to lie all substantially in the common plane 24 (FIG. 1) is the preferred basis for configuring the antenna element structure such that the integral of currents induced in elemental segments of this structure by a wave incident on the antenna from a direction 28 normal to the plane 24 and having a planar wavefront sums to zero at the feed position, i.e. where

the feeder structure 16, 18 is connected to the antenna element structure. In practice, the two elements 10A, 10B are equally disposed and equally weighted on either side of the plane 24, yielding vectoral symmetry about the plane.

The antenna element structure with half-turn helical elements 10A, 10B performs in a manner similar to a simple planar loop, having a null in its radiation pattern in a direction transverse to the axis 12A and perpendicular to the plane 24. The radiation pattern is, therefore, approximately of a figure-of-eight form in both the vertical and horizontal planes transverse to the axis 12A, as shown by FIG. 4. Orientation of the radiation pattern with respect to the perspective view of FIG. 1 is shown by the axis system comprising axes x, y, z shown in both FIG. 1 and FIG. 4. The radiation pattern has two nulls or notches, one on each side of the antenna, and each centred on the line 28 shown in FIG. 1.

The notch in the direction y tends to be somewhat shallower than that in the opposite direction, as shown in FIG. 4, due to the masking of the current-carrying sleeve rim portion 20RA by the longer sleeve portion 20B when the antenna is viewed from the right hand side, as seen in FIG. 1.

The antenna has particular application at frequencies between 200 MHz and 5 GHz. The radiation pattern is such that the antenna lends itself especially to use in a handheld communication unit such as a cellular or cordless telephone handset, as shown in FIG. 5. To orient one of the nulls of the radiation pattern in the direction of the user's head, the antenna is mounted such that its central axis 12A (see FIG. 5) and the plane 24 (see FIG. 1) are parallel to the inner face 30I of the handset 30, and specifically the inner face 30I in the region of the earphone 32. The axis 12A also runs longitudinally in the handset 30, as shown. The more proximal rim portion 20RB of sleeve 20 (FIG. 1) is on the same side of the antenna core as the inner face 30I of the handset. Again, the relative orientations of the antenna, its radiation pattern, and the handset 30 are evident by comparing the axis system x, y, z as it is shown in FIG. 5 with the representations of the axis system in FIGS. 1 and 2.

With a core material having a substantially higher relative dielectric constant than that of air, e.g. ϵ_r=36, an antenna as described above for the DECT band in the region of 1880 MHz to 1900 MHz typically has a core diameter of about 5 mm and the longitudinally extending elements 10A, 10B have an average longitudinal extent (i.e. parallel to the central axis 12A) of about 16.25 mm. The width of the elements 10A, 10B and their branches is about 0.3 mm. At 1890 MHz the length of the balun sleeve 20 is typically in the region of 5.6 mm or less. Expressed in terms of the operating wavelength λ in air, these dimensions are, at least approximately, for the longitudinal (axial) extent of the elements 10A, 10B: 0.102λ, for the core diameter: 0.0315λ, for the balun sleeve: 0.035λ or less, and for the track width: 0.00189λ. Precise dimensions of the antenna elements 10A, 10B can be determined in the design stage by undertaking eigenvalue delay measurements and iteratively correcting for errors on a trial and error basis.

Adjustments in the dimensions of the conductive elements during manufacture of the antenna may be performed in the manner described in our above-mentioned UK Patent Application No. 2292638A with reference to FIGS. 3 to 6 thereof. The whole of the subject matter of this prior application is incorporated in the present application by reference.

The small size of the antenna suits its application in handheld personal communication devices such as mobile telephone handsets. The conductive balun sleeve 20 and/or the conductive layer 22 on the proximal end face 12P of the core 12 allow the antenna to be directly mounted on a printed circuit board or other ground structure in a particularly secure manner. Typically, if the antenna is to be end-mounted, the proximal end face 12P can be soldered to a ground plane on the upper face of a printed circuit board with the inner feed conductor 18 passing directly through a plated hole in the board for soldering to a conductor track on the lower surface. Alternatively, sleeve 20 may be clamped or soldered to a printed circuit board ground plane extending parallel to the axis 12A, with the distal part of the antenna, bearing antenna elements 10A, 10B, extending beyond an edge of the ground plane. It is possible to mount the antenna 10 either wholly within the handset unit, or partially projecting as shown in FIG. 5.

Alternative antennas in accordance with the invention are illustrated in FIGS. 6 to 9.

Referring firstly to FIG. 6, a comparatively simple antenna dispenses with the sleeve balun of FIG. 1, the linking conductors formed by the rim portions of the sleeve in FIG. 1 being replaced by part-annular elongate strip elements 32A, 32B, one of which is connected to the proximal ends 10AAE, 10BBE of the longer antenna element branches 10AA, 10BB, the other being connected to the proximal ends 10ABE, 10BAE of the shorter branches 10AB, 10BA to form conductive loops of different lengths. As in the embodiment of FIG. 1, the ends of the antenna elements lie in a common plane, yielding a generally toroidal radiation pattern with nulls perpendicular to the plane. This antenna, lacking a balun, operates best when coupled to a balanced source or balanced load.

A second alternative antenna, as shown in FIG. 7, has the same antenna element structure as the antenna of FIG. 6, including as it does semicircular elongate linking conductors 32A, 32B extending around the core 12 at different longitudinal positions, but adds a conductive sleeve balun 20 encircling a proximal portion of the core 12 and connected to the outer conductor of the feeder structure as in the antenna of FIG. 1. This allows conversion between balanced and single-ended lines, but with isolation between the linking conductors 32A, 32B being provided solely by their separation from each other and from the sleeve 20.

Referring to FIG. 8, the third alternative antenna is similarly constructed to the second alternative antenna shown in FIG. 7, except that an additional conductive loop is provided by virtue of each elongate helical antenna element 10A, 10B having a divided portion with three branches 10AA, 10AB, 10AC, 10BA, 10BB, and 10BC. As before, each pair of branches is proximally connected together by a respective linking conductor extending around the core 12, but since there are three pairs of branches there are now three respective linking conductors 32A, 32B, 32C. These are located at different longitudinal positions so that the three conductive loops formed by the antenna elements and the linking conductors are each of a different electrical length, thereby defining three resonant frequencies. As in the embodiment of FIG. 7, the conductive balun sleeve 20 is a continuous cylinder, the proximal end of which is connected to the outer conductor of the feeder structure.

The embodiment of FIG. 8 indicates that, depending on the area of the core and the width of the antenna elements, two or more conductive loops can be provided to achieve a required antenna bandwidth. The antenna element ends still lie approximately in a common plane.

Referring to FIG. 9, in a fourth alternative construction, the continuous conductive balun sleeve 20 is used as the

linking conductor for one of the two branches of a dual conductive loop antenna. Thus, the pair of longer antenna element branches **10AA**, **10BB** is connected to the annular rim **20R** of the sleeve **20** at approximately diametrically opposed positions. The pair of shorter branches, **10AB**, **10BB** has an elongate linking conductor **32B** as in the embodiments of FIGS. **6** to **8**, isolated from the sleeve **20**. This combines the advantages of isolation between the linking conductors, the presence of a balun, and an overall length which is less than the second alternative embodiment described above with reference to FIG. **7**.

What is claimed is:

1. A dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising an elongate dielectric core formed of a solid material having a relative dielectric constant greater than 5 and, on or adjacent the surface of the core, a three-dimensional antenna element structure including at least a pair of laterally opposed elongate antenna elements which extend between longitudinally spaced-apart positions on the core, and linking conductors extending around the core to interconnect the elongate elements of the pair, the elongate elements of said pair having respective first ends coupled to a feed connection and linking conductors extending around the core to interconnect the elongate elements of the pair, the elongate elements of said pair having respective first ends coupled to a feed connection and second ends coupled to the linking conductors, wherein for each pair of laterally opposed elongate antenna elements, said elongate elements and said linking conductors together form at least two looped conductive paths each extending from the feed connection to the location spaced lengthwise of the core from the feed connection, then around the core, and back to the feed connection, the electrical length of one of the two paths being greater than that of the other path at an operating frequency of the antenna.

2. An antenna according to claim **1**, having a single pair of laterally opposed elongate antenna elements, each of said elements being forked so as to have a divided portion which extends from a location between said first and second ends to said second end.

3. An antenna according to claim **2**, wherein the divided portion of at least one of the antenna elements comprises branches of different electrical lengths.

4. An antenna according to claim **3**, wherein the electrical length of each branch is in the region of $\lambda/4$ at the resonant frequency of the respective looped conductive path.

5. An antenna according to claim **2**, wherein, for each looped conductive path at its respective resonant frequency, the total electrical length formed by the divided portions and the respective linking conductor is in the region of 180°.

6. An antenna according to claim **2**, wherein each element of said pair is forked at a location corresponding to a voltage maximum at an operating frequency of the antenna.

7. An antenna according to claim **1**, having a plurality of part-annular linking conductors extending around the core, each said elongate antenna element extending between the feed connection and the linking conductors.

8. An antenna according to claim **7**, wherein said first and second ends of said elongate antenna elements lie generally in a common plane, and wherein said linking conductors define a first linking path extending around one side of the core substantially at a first longitudinal location and a second linking path extending around the other side of the core substantially at a different longitudinal location.

9. An antenna according to claim **1**, including a conductive sleeve, and a feeder structure extending longitudinally through the core from a distal end of the core to a proximal end thereof, the feeder structure providing the feed connection at the core distal end and being coupled at the core proximal end to the conductive sleeve to form a ground connection for the sleeve.

10. An antenna according to claim **9**, wherein the electrical length of the sleeve is at least approximately equal to $\lambda/4$ at an operating frequency of the antenna wherein n is an odd number integer.

11. An antenna according to claim **9**, wherein the elongate antenna elements are coupled to a distal rim of the sleeve, which rim constitutes at least one of said linking conductors.

12. An antenna according to claim **2**, including a conductive sleeve, and a feeder structure extending longitudinally through the core from a distal end of the core to a proximal end thereof, the feeder structure providing the feed connection at the core distal end and being coupled at the core proximal end to the conductive sleeve to form a ground connection for the sleeve, wherein the elongate antenna elements are coupled to the sleeve, and wherein each of the divided portions of the antenna elements has branches one of which is connected to the distal rim of a first part of the sleeve to form a linking path around one side of the core and another of which is connected to the distal rim of a second part of the sleeve to form a linking path around the other side of the core, the first and second parts of the sleeve being separated from one another over at least part of their longitudinal extent by a pair of longitudinally extending slits in the conductive material of the sleeve.

13. An antenna according to claim **12**, wherein each slit has a short-circuit end and thereby has an electrical length which is at least approximately equal to one quarter of a wavelength at the said operating frequency.

14. An antenna according to claim **13**, wherein each slit is generally L-shaped.

15. An antenna according to claim **14**, wherein the short-circuited end portions of the slits are directed in opposite directions around the core.

16. An antenna according to claim **12**, wherein the distal rim of the first part of the sleeve extends around the core at one longitudinal location, and the distal rim of the second part of the sleeve extends around the other side of the core at a different longitudinal location.

17. An antenna according to claim **15**, wherein the distal rim of the first part of the sleeve extends around the core at one longitudinal location, and the distal rim of the second part of the sleeve extends around the other side of the core at a different longitudinal location and wherein the short-circuited end portions of the slits are directed towards each other so as to cause a narrowing of the longitudinal conductive path formed by the said sleeve part which has its distal rim nearer the proximal end of the core.

18. An antenna according to claim **2**, wherein the core is substantially cylindrical and each said elongate antenna element is helical, executes p half turns around the core, where p is an integer, and is forked such that the respective divided portion has two parallel helical branches following substantially the same helical path as the undivided portion of the element.

19. An antenna according to claim **18**, further comprising a coaxial feeder structure passing through the core on its central axis from a proximal end to a distal end of the core, wherein the linking conductors are formed by a longitudinally split conductive sleeve connected to the outer conductor of the feeder structure at the core proximal end and having a distal rim connected to branches of the elongate antenna elements, the feeder structure providing the said feed connection at the core distal end where the elongate

antenna elements are coupled respectively to the inner and outer feeder structure conductors.

20. An antenna according to claim **19**, wherein the average axial electrical length of the sleeve is at least approximately equal to λ/4 of the centre of the opening frequency range.

21. A dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising an elongate cylindrical core having a relative dielectric constant greater than 5, and an antenna element structure on the core outer surface comprising a pair of diametrically opposed elongate antenna elements and annularly arranged linking conductors, the elongate elements extending from a feed connection at one end of the core to the linking conductors, wherein the elongate elements are each bifurcated to define, in combination with the linking conductors, two looped conductive paths of different lengths coupled to the feed connection and having different electrical resonant frequencies.

22. An antenna according to claim **21**, wherein the linking conductors are arranged to provide an isolated virtual ground for the bifurcated parts of the elongate elements, and the bifurcation of each elongate element is positioned such that the electrical lengths of the bifurcated parts produce a voltage to current transformation at the respective resonant frequencies of the loop.

23. An antenna according to claim **21**, wherein the ends of the elongate elements lie substantially in a common plane containing the core axis.

24. A handheld radio communication unit having a radio transceiver, an integral earphone for directing sound energy from an inner face of the unit which, in use, is placed against the user's ear, and an antenna as claimed in claim **1**, wherein the first and second ends of the elongate antenna elements lie generally in a common plane and the antenna is mounted in the unit such that the common plane lies generally parallel to the inner face of the unit so that a null in the radiation pattern exists in the direction of the user's head.

25. A dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising an elongate dielectric core formed of a solid material having a relative dielectric constant greater than 5 and, on or adjacent the surface of the core, a three-dimensional antenna element structure including at least a pair of laterally opposed elongate antenna elements which extend between longitudinally spaced-apart positions on the core, and at least one linking conductor extending around the core to interconnect the said elements of the pair, the elongate elements having respective first ends coupled to a feed connection and second ends coupled to at least one said linking conductor, wherein the said elongate elements and the linking conductor or conductors together form at least two looped conductive paths each extending from the feed connection to a location spaced lengthwise of the core from the feed connection, then around the core, and back to the feed connection, the electrical length of one of the two paths being greater than that of the other path and extending around the core on the opposite side thereof from the other path, wherein said linking conductor comprises a conductive sleeve encircling the core, the elongate elements of said pair being connected at their respective second ends to a rim of the sleeve to provide first and second conductive linking paths between the elongate elements around respective opposite sides of the core, and wherein the rim is stepped such that the first linking path extends around one side of the core substantially at a first longitudinal location and the second linking path extends around the other side of the core substantially at a different, second longitudinal location.

26. An antenna according to claim **25**, wherein said first and second ends of said elongate elements lie generally in a common plane.

27. An antenna according to claim **26**, including a feeder structure extending longitudinally through the core from a distal end of the core to a proximal end thereof, the feeder structure providing the feed connection to the core distal end and being coupled at the core proximal end to the conductive sleeve to form a ground connection for the sleeve, wherein the electrical length of the sleeve is at least approximately equal to λ/4 at an operating frequency of the antenna, where n is an odd number integer.

28. A dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising a dielectric core having a central axis and formed of a solid material having a relative dielectric constant greater than 5 and, on or adjacent the surface of the core, a three-dimensional antenna element structure including first and second elongate parts which are laterally opposed with respect to each other and which each comprise at least two mutually adjacent and generally parallel elongate conductors extending between axially spaced-apart positions on the core, and linking conductors extending around the core to interconnect said elongate parts, said elongate parts having respective first ends coupled to a feed connection and second ends coupled to the linking conductors, wherein said first and second elongate parts and said linking conductors together form at least two looped conductive paths each extending from the feed connection to a location spaced lengthwise of the core from the feed connection, then around the core, and back to the feed connection, the electrical length of one of the two paths being greater than that of the other of the two paths at an operating frequency of the antenna.

29. An antenna according to claim **28**, having a single pair of said laterally opposed elongated antenna element structure parts, each of said elongate parts being forked so as to have a divided portion which extends from a location between said first and second ends to said second end and which is formed by said mutually adjacent conductors.

30. An antenna according to claim **28**, wherein the mutually adjacent conductors of at least one of said elongate parts have different electrical lengths.

31. An antenna according to claim **28**, wherein said first and second ends of said elongate antenna element structure parts lie generally in a common plane.

32. An antenna according to claim **28**, including a conductive sleeve, and a feeder structure extending axially through the core from a distal end of the core to a proximal end thereof, the feeder structure providing the feed connection at the core distal end and being coupled at the core proximal end to the conductive sleeve to form a ground connection for the sleeve.

33. An antenna according to claim **32**, wherein the electrical length of the sleeve is at least approximately equal to λ/4 at a operating frequency of the antenna, wherein n is an odd number integer.

34. An antenna according to claim **32**, wherein the elongate antenna element structure parts are coupled to a distal rim of the sleeve, which rim constitutes at least one of said linking conductors.

35. An antenna according to claim **28**, including a conductive sleeve, and a feeder structure extending axially through the core from a distal end of the core to a proximal end thereof, the feeder structure providing the feed connection at the core distal end and being coupled at the core proximal end to the conductive sleeve to form a ground connection for the sleeve, wherein the elongate antenna

element structure parts are coupled to the sleeve, and wherein each of said parts has mutually adjacent generally parallel conductors one of which is connected to the distal rim of a first part of the sleeve to form a linking path around one side of the core and another of which is connected to the distal rim of a second part of the sleeve to form a linking path around the other side of the core, the first and second parts of the sleeve being separated from one another over at least part of their longitudinal extent by a pair of longitudinally extending slits in the conductive material of the sleeve.

36. An antenna according to claim **28**, wherein the core is substantially cylindrical and each side elongate antenna element structure part is helical, executes p half turns around the core, where p is an integer, and the mutually adjacent conductors of each said elongate part comprise parallel helical conductors.

37. An antenna according to claim **36**, further comprising a coaxial feeder structure passing through the core on its central axis from a proximal end to a distal end of the core, wherein the linking conductors are formed by a longitudinally split conductive sleeve connected to the outer conductor of the feeder structure at the core proximal end and having a distal rim connected to said mutually adjacent conductors, the feeder structure providing said feed connection at the core distal end where the elongate antenna elements are coupled respectively to the inner and outer feeder structure conductors.

38. An antenna according to claim **37**, wherein the average axial electrical length of the sleeve is at least approximately equal to $\lambda/4$ at the centre of the operating frequency range.

39. A dielectric-loaded loop antenna for operation at frequencies above 200 MHz comprising a cylindrical core having a relative dielectric constant greater than 5, and an antenna element structure on the cylindrical outer surface of the core comprising a pair of diametrically opposed elongate conductor groups and an annular linking conductor arrangement, the elongate conductor groups extending from a feed connection at one end of the core to the linking conductor arrangement, wherein the conductor groups each include at least two mutually adjacent and parallel conductors, the at least two mutually adjacent and parallel conductors of both elongate conductor groups being arranged in combination with the linking conductor arrangement to define at least two looped conductive paths of different electrical lengths coupled to the feed connection and having different electrical resonant frequencies.

40. An antenna according to claim **39**, wherein the linking conductor arrangement is adapted to provide an isolated virtual ground for said mutually adjacent conductors.

41. An antenna according to claim **39**, wherein each of the conductor groups follows a respective helical path and has ends which lie substantially in a common plane containing the core axis.

42. A handheld radio communication unit, the handheld radio communication unit comprising:

a radio transceiver,

an integral earphone for directing sound energy from an inner face of the unit which, in use, is placed against an ear of a user; and

an antenna comprising:

a dielectric core having a central axis and formed of a solid material having a relative dielectric constant greater than 5 and, on or adjacent the surface of the core, a three-dimensional antenna element structure including first and second elongate parts which are laterally opposed with respect to each other and which each comprise at least two mutually adjacent and generally parallel elongate conductors extending between axially spaced-apart positions on the core, and linking conductors extending around the core to interconnect said elongate parts, said elongate parts having respective first ends coupled to a feed connection and second ends coupled to the linking conductors, wherein said first and second elongate parts and said linking conductors together form at least two looped conductive paths each extending from the feed connection to a location spaced lengthwise of the core from the feed connection, then around the core, and back to the feed connection, the electrical length of one of the two paths being greater than that of the other path at an operating frequency of the antenna, and wherein the first and second ends of the elongate antenna element structure parts lie generally in a common plane and the antenna is mounted in the unit such that the common plane lies generally parallel to the inner face of the unit so that a null in the radiation pattern exists in the direction of the user's head.

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(12) **United States Patent**
Endo et al.

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(45) **Date of Patent: Mar. 20, 2001**

(54) **ANTENNA FEEDING CIRCUIT**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.**[7] **H01Q 1/38**
(52) **U.S. Cl.** **343/895**; 333/115
(58) **Field of Search** 343/895, 858; 333/115, 109, 246

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(57) **ABSTRACT**

An object of the present invention is to provide an antenna feeding circuit, which requires no balance-unbalance converter and has a simplified structure.

The object is attained, by an antenna feeding circuit, according to the present invention, in which micro-strips lines are constituted from one or more pair(s) of band conductors (*5a*, *5b*) disposed on the outer surface of the cylindrical body (1) and an inner conductor (6) disposed on the whole of the inner surface of the cylindrical body (1). A 180 degree distributor (2) supplies electric power to the band conductors (*5a*, *5b*) so that the phase difference between the currents in the band conductors (*5a*, *5b*) is 180 degrees.

Inutile current induced in the inner surface of the inner conductor can be cancelled out, because the inner conductor 6 is disposed on the whole of the inner surface of the cylindrical body (1).

9 Claims, 8 Drawing Sheets

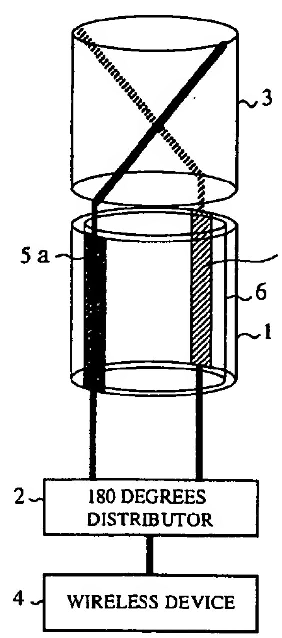


FIG. 1

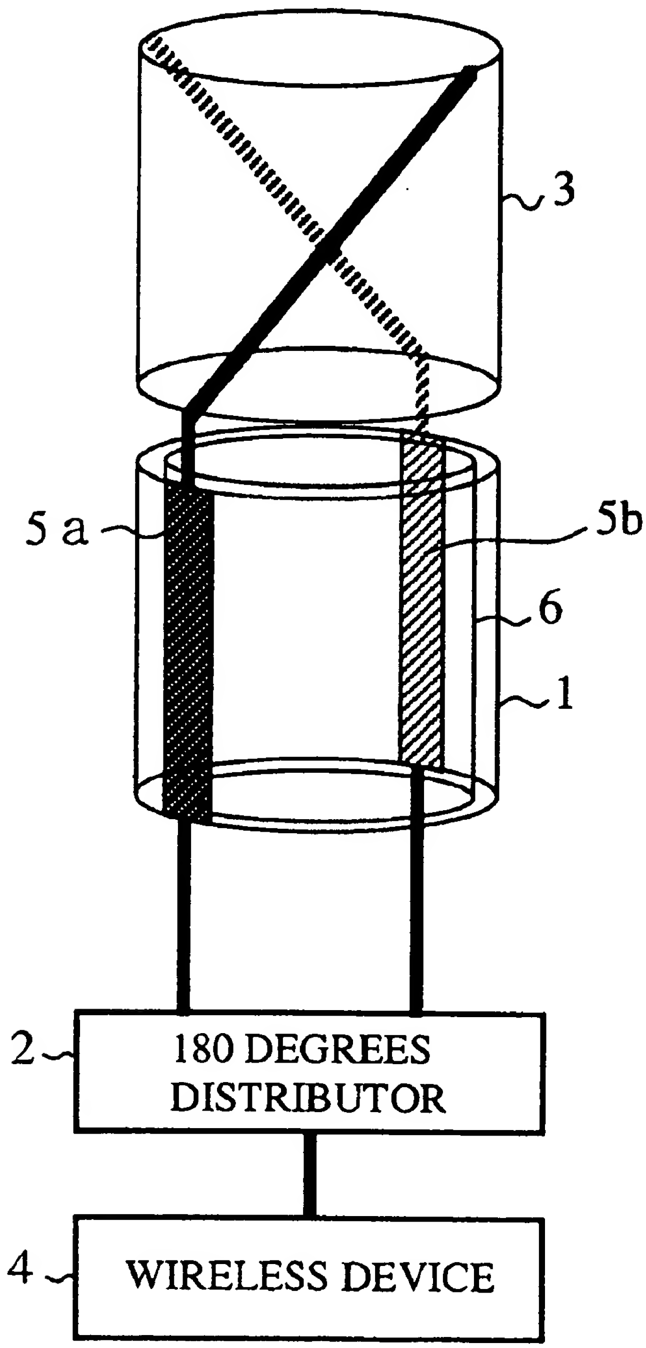


FIG.2

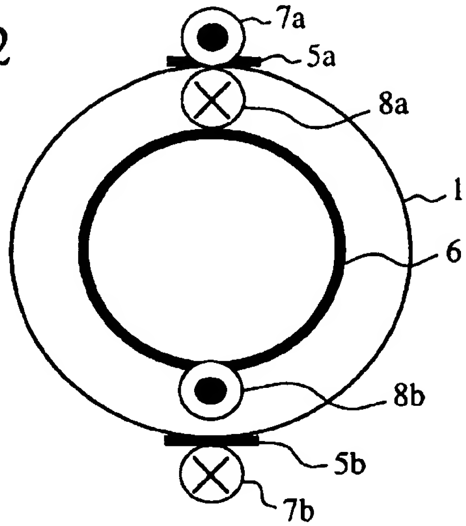


FIG.3

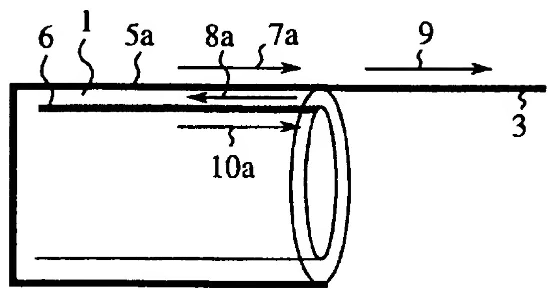


FIG.4

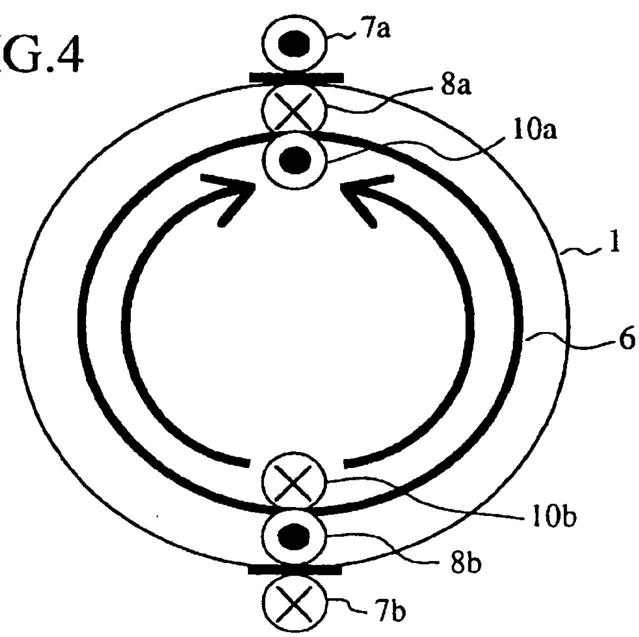


FIG.5

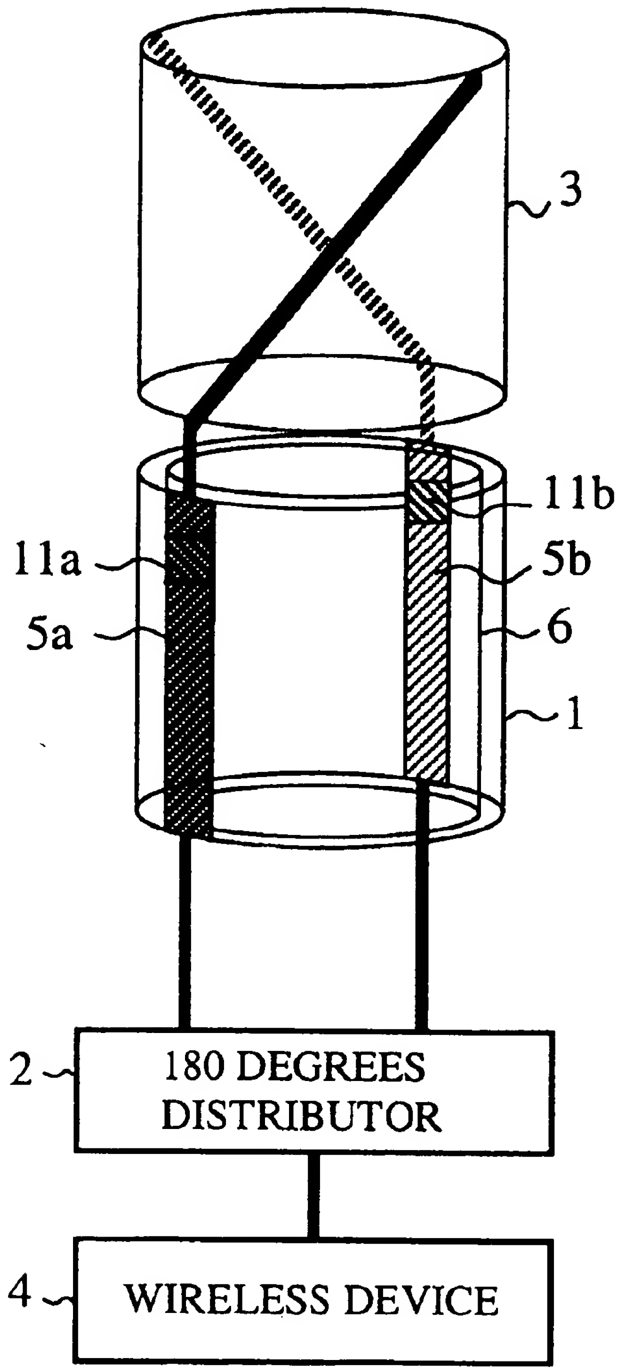

3
11b
11a
5b
5a
6
1
2
180 DEGREES DISTRIBUTOR
4
WIRELESS DEVICE

FIG.6

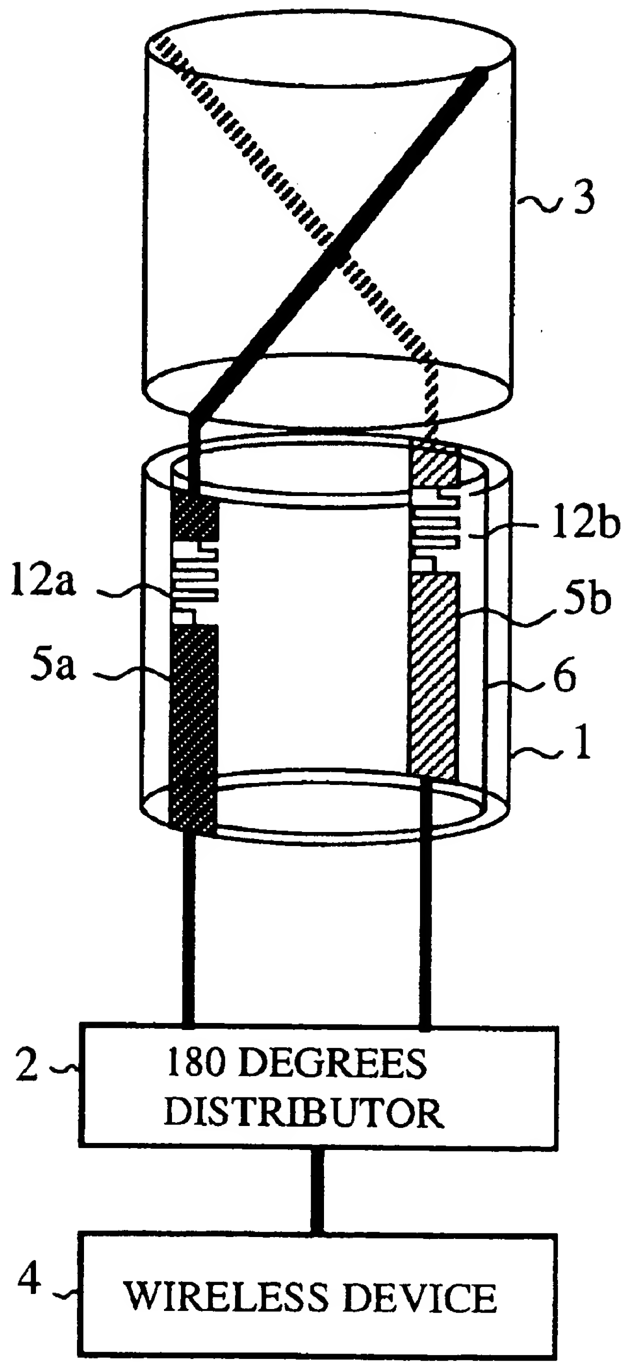

3
12b
12a
5b
5a
6
1
2
180 DEGREES DISTRIBUTOR
4
WIRELESS DEVICE

FIG.7

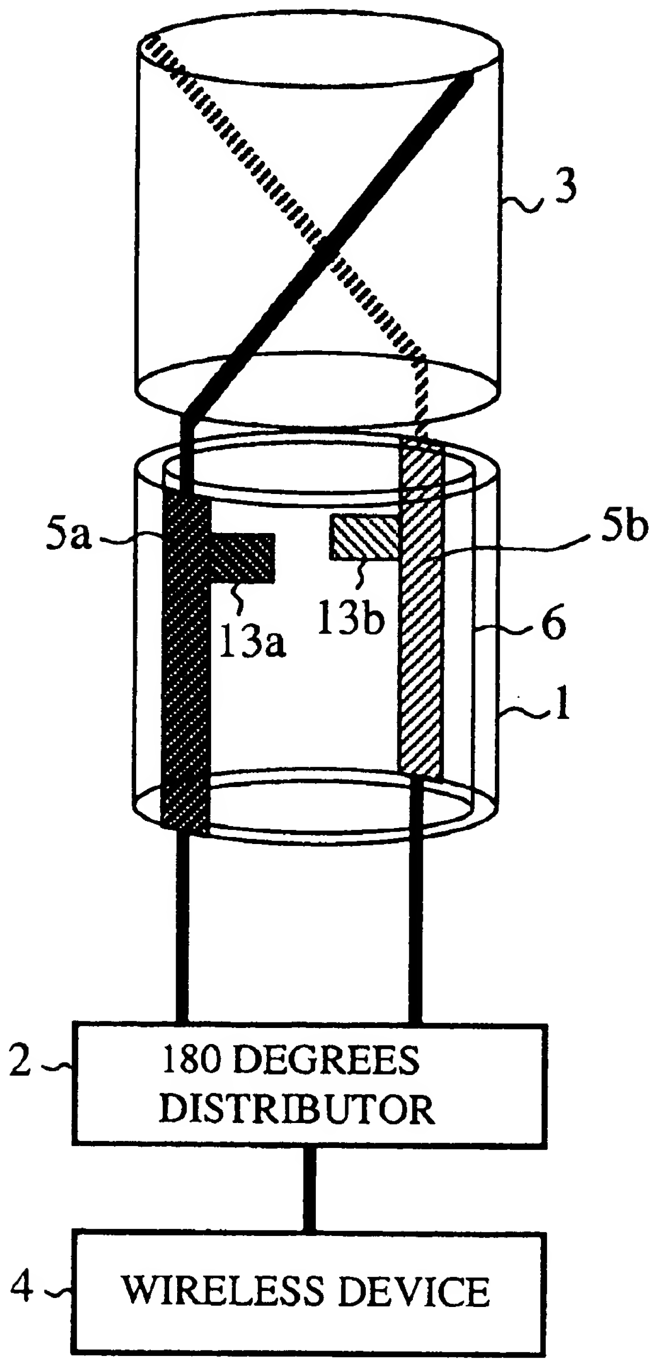

3
5a
5b
13a
13b
6
1
2
180 DEGREES DISTRIBUTOR
4
WIRELESS DEVICE

FIG.8

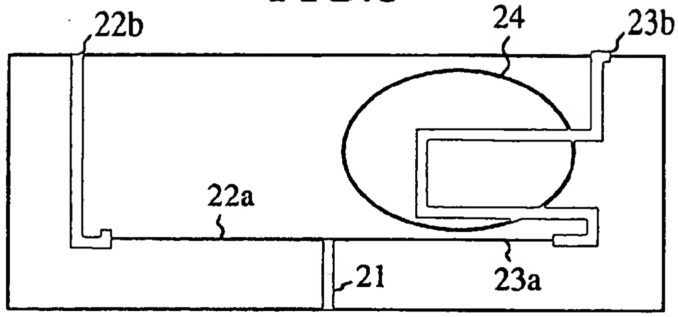


FIG.9

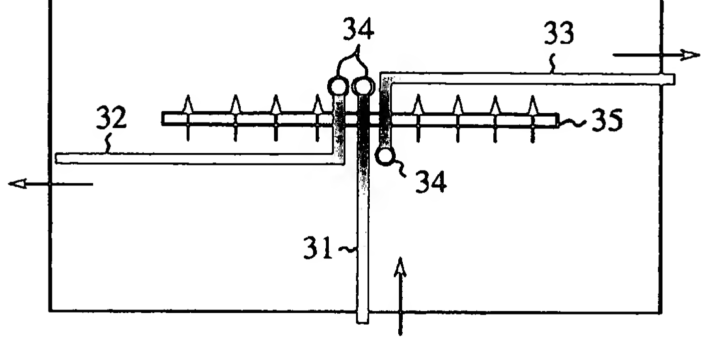


FIG.12

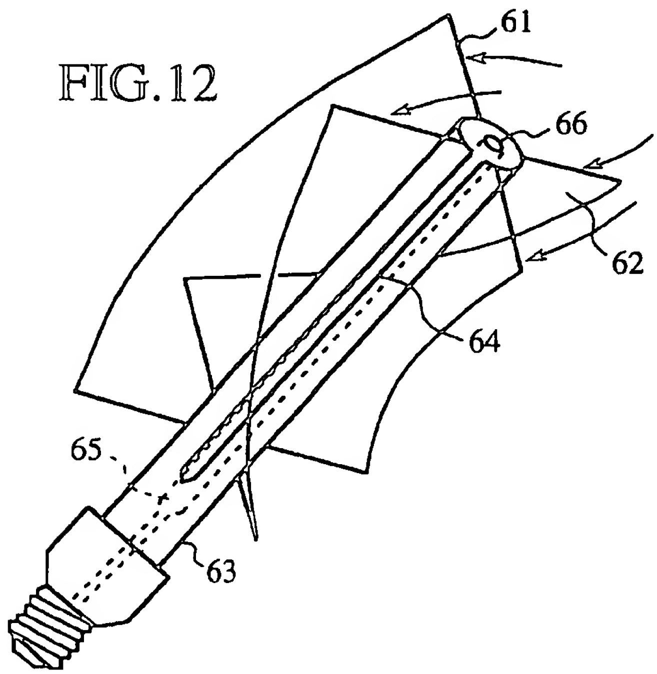


FIG.10

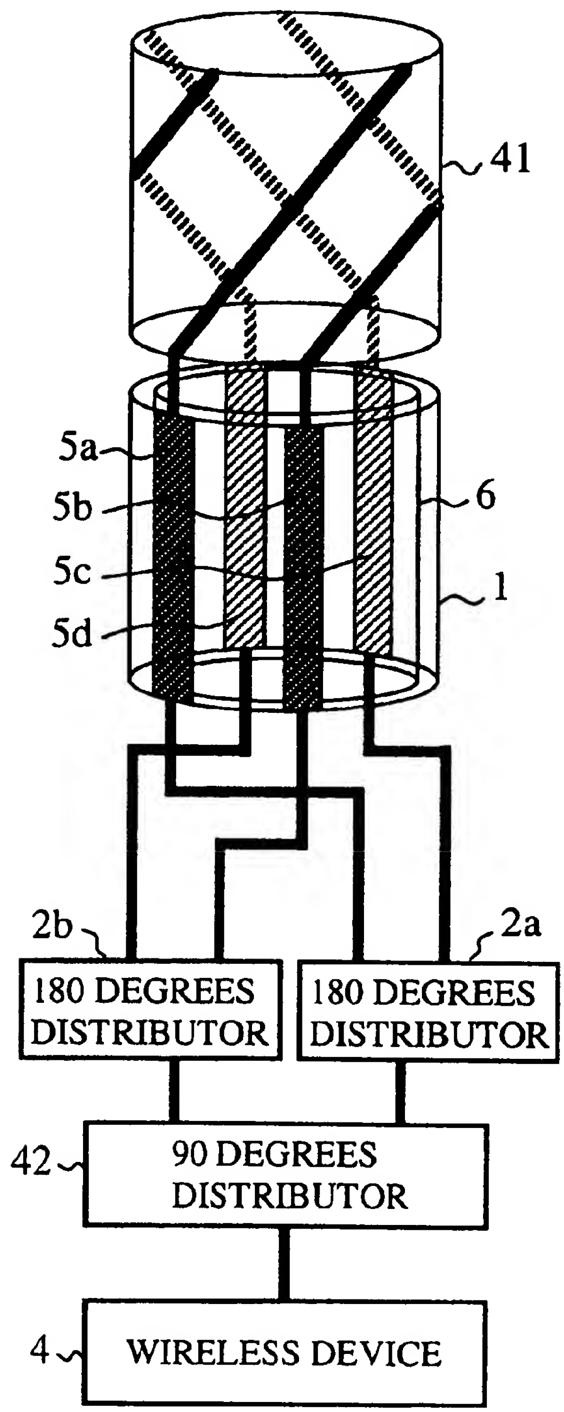
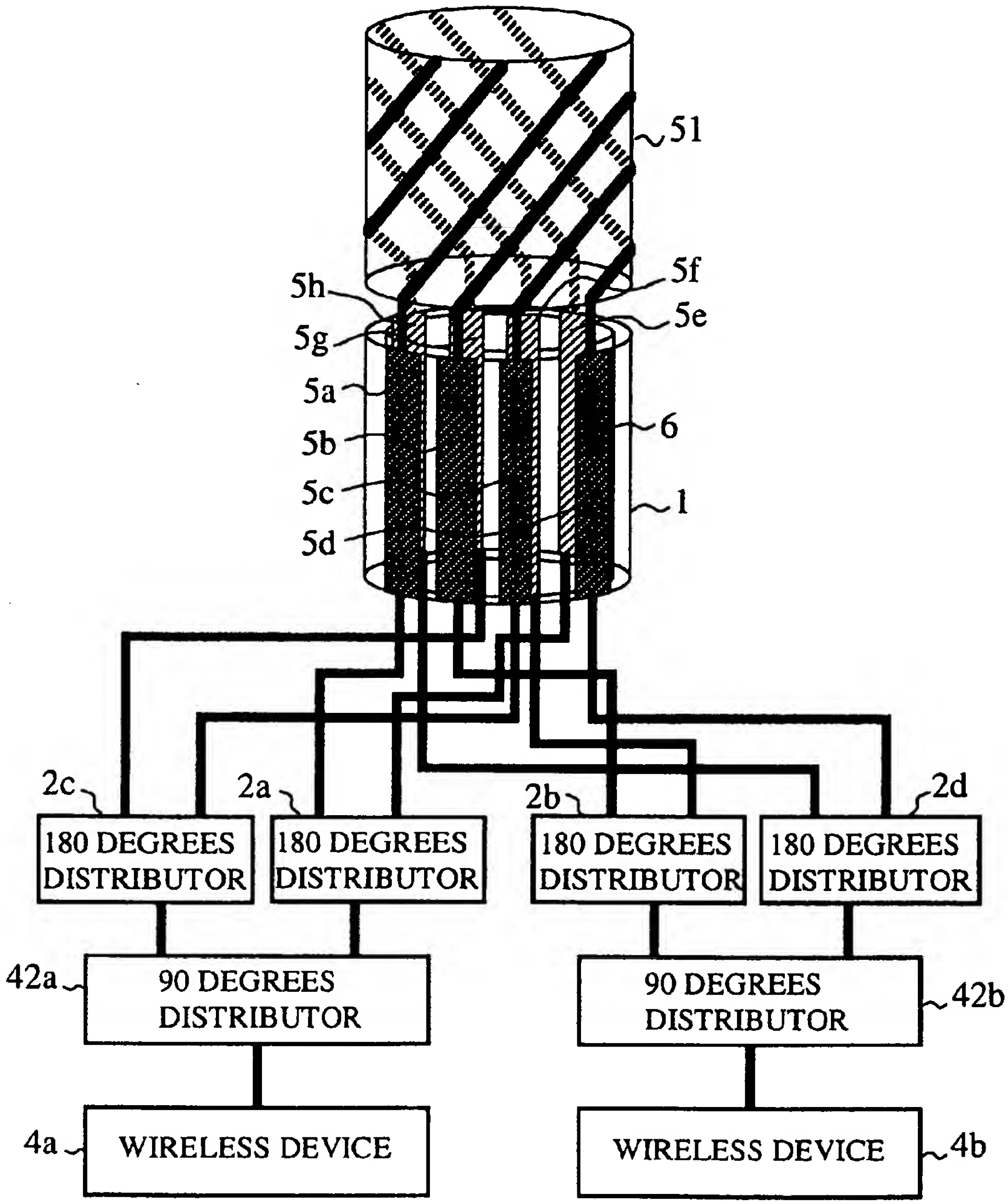

41
5a
5b
5c
5d
6
1
2b
2a
180 DEGREES DISTRIBUTOR
180 DEGREES DISTRIBUTOR
42
90 DEGREES DISTRIBUTOR
4
WIRELESS DEVICE

FIG.11


51
5h
5f
5g
5e
5a
6
5b
5c
1
5d
2c
2a
2b
2d
180 DEGREES DISTRIBUTOR
180 DEGREES DISTRIBUTOR
180 DEGREES DISTRIBUTOR
180 DEGREES DISTRIBUTOR
42a
90 DEGREES DISTRIBUTOR
90 DEGREES DISTRIBUTOR
42b
4a
WIRELESS DEVICE
WIRELESS DEVICE
4b

ANTENNA FEEDING CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to an antenna feeding circuit for an helical antenna, especially, a bifilar, quadrifilar and an octifilar helical antenna. A bifilar helical antenna is a helical antenna furnished with two filaments, a quadrifilar helical antenna is a helical antenna furnished with four filaments and an octifilar helical antenna is a helical antenna furnished with eight filaments.

2. Description of the prior art

Such an antenna feeding circuit is known, for example, from a "¼ turn volute with split sheath balun" shown in FIG. 6 in "Resonant Quadrifilar Helix Antenna" disclosed in "Microwave Journal", December, 1970, p49–53.

FIG. **12** is a schematic perspective view of an antenna feeding circuit in the prior art, more specifically, it shows a ¼ turn volute with split sheath balun disclosed in the article. In the figure, reference numerals **61, 62** denote, respectively, a first helical antenna element and a second helical antenna element. Reference numerals **63, 64** denote, respectively, a coaxial cable for feeding the helical antenna and a ¼ wavelength slit disposed on the outer conductor of the coaxial cable **63**. Reference numeral **65** denotes an impedance converter disposed on the inner conductor of the coaxial cable **63**. Electric power is fed to the first and second helical antenna elements **61, 62** from an electric power feeding point **66**.

Regarding the function, the first and second helical antenna elements **61, 62** can be assumed to be balanced lines, similar to a pair of parallel two lines. When unbalanced lines, for example, such as a coaxial cable, are connected to a helical antenna, a balance-unbalance converter is required between the helical antenna elements **61, 62** and the coaxial cable. Therefore, a balun, constituted by the coaxial cable **63**, the ¼ wavelength slit **64** and the impedance converter **65**, is disposed as a balance-unbalance converter. Another function of this balun is to cancel out an inutile current, which appears when a balanced line is connected to an unbalanced line.

Japanese Patent Application 63-30006-A discloses another antenna feeding circuit, which comprises a ¼ wavelength slit disposed on the outer conductor of a coaxial cable. The antenna comprises two sets of antenna elements, having an equal pitch angle, and each set of antenna elements is connected to one of two connecting portions of a connecting piece. The structure of this antenna feeding circuit facilitates the assembling of the antenna, and improves the preciseness of dimensions of the components of the antenna feeding circuit.

The antenna feeding circuits in the prior arts have following drawbacks due to such structures:

A balun is of a rather long dimension, i.e., ¼ wavelength, in the longitudinal direction of an antenna;

The structure is rather complicated, as for example, when a coaxial structure of the antenna portion and the feeding circuit portion is employed to shorten the total length of the system including the length of the antenna portion.

SUMMARY OF THE INVENTION

An object of the present invention is to propose an antenna feeding circuit, which can eliminate such drawbacks in the prior art.

Another object of the present invention is to propose an antenna feeding circuit, which requires no balance-

unbalance converter (balun), such as used in the prior art, and has a simple structure.

The objects are attained by the antenna feeding circuit, according to the present invention, comprising:

- an inner conductor disposed on the inner surface of a cylindrical body;
- a pair of band conductors disposed on the outer surface of the cylindrical body at a position symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder;
- a 180 degree distributor, connected to an end of each of the band conductors, for supplying electric power to each of the band conductors, so that the phase difference between the currents in the band conductors is 180 degrees; and
- a helical antenna, each element of the helical antenna corresponds to one of the band conductor and is connected to the other end of the band conductors.

In an embodiment of the antenna feeding circuit according to the present invention, the band conductors comprise an impedance matching circuit.

In an embodiment of the antenna feeding circuit according to the present invention, the band conductors comprise a capacitor element as an impedance matching circuit.

In an embodiment of the antenna feeding circuit according to the present invention, the band conductors comprise a meander line as an impedance matching circuit.

In an embodiment of the antenna feeding circuit according to the present invention, the band conductors comprise a short stub as an impedance matching circuit.

In an embodiment of the antenna feeding circuit according to the present invention, the 180 degree distributor comprises:

- a T-branching circuit having an input terminal and a pair of output terminals, which are T-branched from the input terminal; and
- a delay line connected to either of the output terminals, the electric length of the delay line is identical to a half of the wavelength at the frequency in use.

In an embodiment of the antenna feeding circuit according to the present invention, the 180 degree distributor comprises: a T-branching circuit comprising a first micro-strips line as an input terminal and a second and third micro-strips lines as output terminals, which are T-branched from the first micro-strips line; and a slot disposed on the substrate of the T-branching circuit so as to be perpendicular to the first micro-strips line, the length of the slot is substantially a half of the wavelength of the frequency in use; wherein the first micro-strips line is grounded to the substrate at a point in the opposite side to the input side of the first micro-strips line with respect to the slot; the second micro-strips line is disposed at the same side to the input side of the first micro-strips line and is grounded to the substrate at a point in the opposite side to the input side of the first micro-strips line with respect to the slot; the third micro-strips line is disposed at the opposite side to the input side of the first micro-strips line and is grounded to the substrate at a point in the same side to the input side of the first micro-strips line with respect to the slot.

The antenna feeding circuit according to an embodiment of the present invention comprises: an inner conductor disposed on the inner surface of a cylindrical body; first and second pairs of band conductors disposed on the outer surface of the cylindrical body at a position symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder; first and

second 180 degree distributors connected to an end of a band conductor in each pair of the band conductors, for supplying electric powers to each of the band conductors, so that the phase difference between the currents in the band conductors in each group of the band conductors is 180 degrees; a 90 degree distributor connected to the first and second 180 degree distributor, for supplying electric power to each of the first and second 180 degree distributors so that the phase difference between the input electric power to the first and second 180 degree distributors is 90 degrees; and a quadrifilar helical antenna, each element of the quadrifilar helical antenna corresponds to one of the band conductor and is connected to the other end of the band conductor.

The antenna feeding circuit according to an embodiment of the present invention comprises: an inner conductor disposed on the inner surface of a cylindrical body; first to fourth pairs of band conductors disposed on the outer surface of the cylindrical body at a position symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder; first to fourth 180 degree distributors, connected to an end of a band conductor in each pair of the band conductors, for supplying electric power to each of the band conductors, so that the phase difference between the currents in the band conductors in each pair of the band conductors is 180 degrees; a first 90 degree distributor connected to the first and third 180 degree distributor, for supplying electric power to each of the first and third 180 degree distributors so that the phase difference between the input electric power to the first and third 180 degree distributors is 90 degrees; a second 90 degree distributor connected to the second and fourth 180 degree distributor, for supplying electric power to each of the second and fourth 180 degree distributors so that the phase difference between the input electric power to the second and fourth 180 degree distributors is 90 degrees; and an octifilar helical antenna comprised of two sets of quadrifilar helical antenna, elements in each set of quadrifilar helical antenna are connected to the other end of a band conductor in the first to fourth pair of the band conductors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an antenna feeding circuit according to the first embodiment of the present invention.

FIG. 2 is a cross-sectional view of a cylindrical body in an antenna feeding circuit according to the first embodiment of the present invention, showing the directions of currents flowing in band conductors.

FIG. 3 shows the directions of currents flowing in a band conductor according to the first embodiment and a helical antenna connected with the band conductor.

FIG. 4 is a cross-sectional view of a cylindrical body in an antenna feeding circuit according to the first embodiment of the present invention, showing the directions of currents flowing in the band conductors and in the inner conductor, when a helical antenna is connected to the band conductor.

FIG. 5 is a schematic view of an antenna feeding circuit according to the second embodiment of the present invention.

FIG. 6 is a schematic view of an antenna feeding circuit according to the third embodiment of the present invention.

FIG. 7 is a schematic view of an antenna feeding circuit according to the fourth embodiment of the present invention.

FIG. 8 is a schematic view of a 180 degree distribution circuit in an antenna feeding circuit according to the fifth embodiment of the present invention.

FIG. 9 is a schematic view of a 180 degree distribution circuit in an antenna feeding circuit according to the sixth embodiment of the present invention.

FIG. 10 is a schematic view of an antenna feeding circuit according to the seventh embodiment of the present invention.

FIG. 11 is a schematic view of an antenna feeding circuit according to the eighth embodiment of the present invention.

FIG. 12 is a schematic view of an antenna feeding circuit in the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Embodiments of the present invention are explained below.

EMBODIMENT 1

FIG. 1 is a schematic view of an antenna feeding circuit according to the first embodiment of the present invention. Reference numeral **1** denotes an electrically insulating cylindrical body. A pair of band conductors ***5a***, ***5b*** are disposed on the outer surface of the cylindrical body **1** at positions symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder. The whole of the inner surface of the cylindrical body **1** is covered with an inner conductor **6**. The band conductors ***5a***, ***5b***, the cylindrical body **1** and the inner conductor **6** form micro-strips lines.

A 180 degree distributor **2** is connected to an end of each band conductors **2**, which supplies electric power to the band conductors ***5a***, ***5b***, so that the phase difference between the currents supplied to the band conductors is 180 degrees. A bifilar helical antenna **3** is connected to the other end of the band conductors ***5a***, ***5b***. Reference numeral **4** denotes a wireless device, which provides electric power to the 180 degree distributor **2**.

The function of the antenna feeding circuit according to the first embodiment of the present invention is explained below.

FIG. 2 is a cross-sectional view of a cylindrical body in an antenna feeding circuit according to the first embodiment of the present invention, showing the directions of currents flowing in band conductors.

The 180 degree distributor **2** supplies electric power to the band conductors ***5a***, ***5b***, so that a phase difference between the currents in the band conductors is 180 degrees. Therefore, the directions of the current ***7a***, ***7b*** flowing in the band conductors ***5a***, ***5b*** are inverse to each other. Each current ***7a***, ***7b*** induces currents ***8a***, ***8b*** on the outer surface of the inner conductor **6** at a position corresponding to each of the band conductors ***5a***, ***5b***, because they form micro-strips lines. The directions of the induced current ***8a***, ***8b*** are inverse to each other. The induced currents ***8a***, ***8b*** flow in the inner conductor **6** covering the inner surface of the cylindrical body, so that the directions of the induced current ***8a***, ***8b*** are inverse to each other.

FIG. 3 shows the directions of currents flowing in a band conductor according to the first embodiment and a helical antenna connected with the bane conductor. The current ***7a*** flowing in the band conductor ***5a*** flows into one of the bifilar antenna elements **3**, as an antenna current **9**. However, the induced current ***8a*** flowing on the outer surface of the inner conductor **6** corresponding to the current ***7a*** in the band conductor ***5a*** induces an inverse inutile current ***10a*** on the inner surface of the inner conductor **6**. Similarly, the current ***7b*** (not shown) flowing in the band conductor ***5b*** induces an inutile current ***10b*** (not shown) on the inner surface of the

inner conductor 6 at a corresponding portion. When these inutile currents flow into the 180 degree distributor 2 and to the wireless device 4, the functions of antenna system will be influenced by these inutile currents, and an inutile electromagnetic wave will be emitted.

FIG. 4 is a cross-sectional view of a cylindrical body 1 in an antenna feeding circuit according to the first embodiment of the present invention, showing the directions of currents flowing in the band conductors 5*a*, 5*b* and in the inner conductor 6, when a helical antenna 3 is connected to the band conductor 5*a*, 5*b*. It can be seen from the figure that the directions of the inutile currents 10*a*, 10*b*, which respectively corresponding to the band conductors 5*a*, 5*b*, are inverse to each other. However they are cancelled out by each other, because they are connected to each other by the inner conductor 6 disposed on the whole of the inner surface of the cylindrical body 1. Therefore the antenna system is not influenced by the inutile currents 10, 10*b*. As a result, it is not necessary to use a balanced-unbalanced converter, i.e., a balun, which is used in such an antenna system in the prior art.

As explained above, according to the first embodiment, a pair of band conductors 5*a*, 5*b* disposed on the outer surface of the cylindrical body 1 and the inner conductor 6 disposed on the whole of the inner surface of the cylindrical body 1 form micro-strips lines respectively, and a 180 degree distributor 2 supplies electric power to the pair of the band conductor 5*a*, 5*b*. The induced inutile currents in the inner conductor are cancelled out by each other, because the inner conductor is disposed on the whole of the inner surface of the cylindrical body. As a result, a balance-unbalance converter, a balun, is not necessary, and the structure of the antenna feeding circuit can be simplified.

EMBODIMENT 2

FIG. 5 is a schematic view of an antenna feeding circuit according to the second embodiment of the present invention. In this embodiment, a chip capacitor 11*a*, 11*b* as a capacitor element is connected to each of the band conductors 5*a*, 5*b*. The capacitor element is not limited to a chip element 11*a*, 11*b*, and can be replaced by any other capacitor element. Components in the figure identical to those in the first embodiment shown in FIG. 1 are referred to the same reference numerals.

The function of the antenna feeding circuit according to the second embodiment of the present invention is explained below.

The band conductor 5*a*, 5*b* and the inner conductor 6 disposed on the whole of the inner surface of the cylindrical body 1 form micro-strips lines, respectively, so that the inutile currents in the inner conductor are cancelled out by each other in like manner as in the first embodiment. Furthermore the impedance matching between the band conductors 5*a*, 5*b* and the bifilar helical antenna element 3 is carried out by the chip capacitors 11*a*, 11*b* connected to the band conductors 5*a*, 5*b*.

According to the second embodiment, advantages can be obtained in that the structure of the antenna feeding circuit can be simplified; and that electric power can be effectively supplied to the bifilar antenna elements 3, using chip capacitors 11*a*, 11*b* as impedance matching elements, so that the efficiency of the electromagnetic wave radiation can be improved.

EMBODIMENT 3

FIG. 6 is a schematic view of an antenna feeding circuit according to the third embodiment of the present invention. In this embodiment, meander lines 12*a*, 12*b* are connected respectively to the band conductors 5*a*, 5*b*. Components in the figure identical to those in the first embodiment shown in FIG. 1 are referred to the same reference numerals.

The function of the antenna feeding circuit according to the third embodiment of the present invention is explained below.

The band conductors 5*a*, 5*b* and the inner conductor 6 disposed at the whole of the inner surface of the cylindrical body 1 form micro-strips lines, respectively, so that the inutile currents in the inner conductor are cancelled out to each other in like manner as in the first embodiment. Furthermore the impedance matching between the band conductors 5*a*, 5*b* and the bifilar helical antenna element 3 are carried out by the meander lines 12*a*, 12*b* connected to the band conductors 5*a*, 5*b*.

As explained, according to the third embodiment, advantages can be obtained in that the structure of the antenna feeding circuit can be simplified; and that electric power can be effectively supplied to the bifilar antenna elements 3, using meander lines 12*a*, 12*b* as impedance matching elements, so that the efficiency of the electromagnetic wave radiation can be improved.

EMBODIMENT 4

FIG. 7 is a schematic view of an antenna feeding circuit according to the fourth embodiment of the present invention. In this embodiment, short stubs 13*a*, 13*b* are connected to the band conductors 5*a*, 5*b*. Components in the figure identical to those in the first embodiment shown in FIG. 1 are referred to the same reference numerals.

The function of the antenna feeding circuit according to the fourth embodiment of the present invention is explained below.

The band conductor 5*a*, 5*b* and the inner conductor 6 disposed at the whole of the inner surface of the cylindrical body 1 form micro-strips lines, so that the inutile currents in the inner conductor are cancelled out to each other in like manner as in the first embodiment. Furthermore the impedance matching between the band conductors 5*a*, 5*b* and the bifilar helical antenna element 3 are carried out by the short stubs 13*a*, 13*b* connected to each of the band conductors 5*a*, 5*b*.

According to the fourth embodiment, advantages can be obtained in that the structure of the antenna feeding circuit can be simplified; and that electric power can be effectively supplied to the bifilar antenna elements 3, using short stubs 13*a*, 13*b* as impedance matching elements, so that the efficiency of the electromagnetic wave radiation can be improved.

EMBODIMENT 5

FIG. 8 is a schematic view of a 180 degree distribution circuit in an antenna feeding circuit according to the fifth embodiment of the present invention. In the figure, reference numerals 21, 22*a*, 23*a* denote, respectively, an input terminal of a T-branching circuit constituted from a micro-strips line, an output terminal of the T-branching circuit and another output terminal of the T-branching circuit. Reference numeral 24 denotes a delay micro-strips line for phase delay of 180 degrees at the using frequency, which is half of the characteristic electric length at the using frequency. Reference numerals 22*b*, 23*b* denote respectively micro-strips lines.

The function of the antenna feeding circuit according to the fifth embodiment of the present invention is explained below.

The electric power inputted from the input terminal 21 is distributed to the output terminals 22a, 23a at an equal amplitude and an equal phase. The phase of the current distributed to the output terminal 23a delays at 180 degrees due to the delay micro-strips line 24. As a result, a phase difference of 180 degrees appears between the outputs from the micro-strips line 22b, 23b.

According to the fifth embodiment, the structure of the antenna feeding circuit can be simplified.

EMBODIMENT 6

FIG. 9 is a schematic view of a 180 degree distribution circuit in an antenna feeding circuit according to the sixth embodiment of the present invention. A T-branching circuit is constituted from three micro-strips lines 31, 32, 33. A first micro-strips line 31 is the input terminal of a T-branching circuit. Reference numeral 35 denotes a slot disposed in the substrate of the micro-strips lines so as to be perpendicular to the micro-strips line 31. The length of the slot 35 is substantially half of the wavelength at the using frequency, namely, half of the electric length at the using frequency. There are three through-holes 34 on the substrate. The first micro-strips line 31 is grounded to the substrate through a through-hole 34, which is disposed at a point where the first micro-strips line 31 just crossed over the slot 35 to the opposite side.

The second micro-strips line 32 is disposed at the same side as the first micro-strips line 31 and is grounded to the substrate through another through-hole 34, which is disposed at a point where the second micro-strips line 32 just crossed over the slot 35 to the opposite side.

The third micro-strips line 33 is disposed at the opposite side to the first micro-strips line 31 with respect to the slot 35 and is grounded to the substrate through a through-hole 34, which is disposed at a point where the third micro-strips line 33 just crossed over the slot 35 to the same side as the first micro-strips line 31. The function of the antenna feeding circuit according to the sixth embodiment of the present invention is explained below.

The electric power inputted from the micro-strips line 31 propagates along the micro-strips line 31 and induces an electric field in the slot 35. The induced electric field in the slot 35, in turn, induces electric fields in the second and third micro-strips lines 32, 33. The coupled field in the second micro-strips line 32 propagates in the equal phase as that of the first micro-strips line 31, because the first and second micro-strips lines 31, 32 are disposed at the same side with respect to the slot 35 and cross over the slot 35 in the same direction.

On the other hand, because the first and third micro-strips lines 31, 33 are disposed at the opposite side with respect to the slot 35, and they cross over the slot 35 in the opposite directions, the phase of the coupled electric field in the third micro-strips line 33 is inverse to the exiting field in the first micro-strips line 31. As a result, electric fields propagating in the second and third micro-strips lines 32, 33 have a phase difference of 180 degrees to each other. Consequently, the system as a whole functions as a 180 degree distributor.

According to the sixth embodiment, the structure of the antenna feeding circuit can be simplified.

EMBODIMENT 7

FIG. 10 is a schematic view of an antenna feeding circuit according to the seventh embodiment of the present invention. Reference numeral 1 denotes an electrically insulating cylindrical body. Four band conductors 5a, 5b, 5c, 5d are disposed equidistantly on the outer surface of the cylindrical body 1 at positions symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder. The band conductors are grouped into two pairs 5a, 5c and 5b, 5d. The whole of the inner surface of the cylindrical body 1 is covered with an inner conductor 6. The band conductors 5a, 5b, 5c, 5d, the cylindrical body 1 and the inner conductor 6 form micro-strips lines.

A first 180 degree distributors 2a is connected to an end of band conductors 5a, 5c, so as to supply electric power to each of the band conductors 5a, 5c, so that the phase difference of the currents flowing in them is 180 degrees. A second 180 degree distributors 2b is connected to an end of band conductors 5b, 5d, so as to supply electric power to the band conductors 5b, 5d, so that the phase difference of the current flowing in them is 180 degrees. A quadrifilar helical antenna 41 is connected to the other end of the band conductors 5a, 5b, 5c, 5d. A 90 degree distributor 42 supplies electric power to each of the first and second 180 degree distributors 2a, 2b so that the phase difference between the currents in the first and second 180 degree distributors is 90 degrees. Reference numeral 4 denotes a wireless device, which provides electric power to the 90 degree distributor 42.

The function of the antenna feeding circuit according to the seventh embodiment of the present invention is explained below.

Four band conductors 5a, 5b, 5c, 5d disposed on the outer surface of the cylindrical body and the inner conductor 6 disposed on the inner surface of the cylindrical body 6 form four micro-strips lines. Four band conductors 5a, 5b, 5c, 5d are grouped into two groups 5a, 5c and 5b, 5c. The band conductors in each group are configured at opposite positions on the outer surface of the cylindrical body. The former group 5a, 5c are connected to the first 180 degree distributor 2a, the later group 5b, 5d are connected to the second 180 degree distributors. The other ends of the band conductors 5a, 5b, 5c, 5d are connected respectively to a corresponding element of the quadrifilar antenna 41.

Because each group of the band conductors 5a, 5c; 5b, 5d are connected respectively with the first and second 180 degree distributors 2a, 2b, the inutile current induced in the inner surface of the inner conductor 6 can be cancelled out, in like manner as in the first embodiment.

Furthermore, the phase difference of the input signals to the first and second 180 degree distributors 2a, 2b is 90 degrees. Therefore the phases of the currents in the neighboring band conductors 5a, 5b, 5c, 5d connected to the first and second 180 degree distributors 2a, 2b differ by 90 degrees in a cyclic manner. And, the phases of the currents in the neighboring antenna elements in the quadrifilar antenna 41 connected to the band conductors differ by 90 degrees in a cyclic manner.

As explained, according to the seventh embodiment, band conductors 5a, 5b, 5c, 5d disposed on the outer surface of the cylindrical body 1 and the inner conductor 6 disposed on the whole of the inner surface of the cylindrical body 1 form micro-strips lines, and two 180 degree distributors 2a, 2b supplies electric power to the each group of band conductors 5a, 5c; 5b, 5d so that the phase difference between the currents in the band conductors in each group is 90 degrees. And the induced inutile currents in the inner surface of the inner conductor 6 can be cancelled out, because the inner conductor 6 is disposed on the whole of the inler surface of

the cylindrical body 1. As a result, it is not necessary to use a balance-unbalance converter, i.e., a balun. And the structure of the antenna feeding circuit can be simplified. Furthermore, antenna feeding circuits for many antenna elements can be unified, when the outer surface of the cylindrical body are partitioned equidistantly for the band conductors.

EMBODIMENT 8

FIG. 11 is a schematic view of an antenna feeding circuit according to the eighth embodiment of the present invention. Reference numeral 1 denotes an electrically insulating cylindrical body. Eight band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h** are disposed equidistantly on the outer surface of the cylindrical body 1 at positions symmetrical with respect to the axis of the cylinder so as to be parallel with the longitudinal direction of the cylinder. The band conductors are grouped into four pairs **5a, 5e; 5b, 5f; 5c, 5g;** and **5d, 5h**. The whole of the inner surface of the cylindrical body 1 is covered with an inner conductor 6. Each of the band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h**, the cylindrical body 1 and the inner conductor 6 form a micro-strips line.

A first 180 degree distributor **2a** is connected to an end of band conductors **5a, 5e**, so as to supply electric powers to each of the band conductors **5a, 5e**, so that the phase difference of the currents in the band conductors is 180 degrees. A second 180 degree distributor **2b** is connected to an end of band conductors **5b, 5f**, so as to supply electric powers to the band conductors **5b, 5f**, so that the phase difference of the currents in the band conductors is 180 degrees. A third 180 degree distributor **2c** is connected to an end of band conductors **5c, 5g**, so as to supply electric power to each of the band conductors **5c, 5g**, so that the phase difference of the currents in the band conductors is 180 degrees. A fourth 180 degree distributor **2d** is connected to an end of band conductors **5d, 5h**, so as to supply electric power to the band conductors **5d, 5h**, so that the phase difference of the currents in the band conductors is 180 degrees.

An octifilar helical antenna 51 is connected to the other end of the band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h**. A first 90 degree distributor **42a** supplies electric power to each of the first and third 180 degree distributors **2a, 2c** so that the phase difference between the currents in them is 90 degrees. A second 90 degree distributor **42b** supplies electric power to each of the second and fourth 180 degree distributors **2b, 2d** so that the phase difference between the currents in them is 90 degrees. Reference numeral **4a** denotes a first wireless device, which provides electric power to the first 90 degree distributor **42a**. Reference numeral **4b** denotes a second wireless device, which provides electric power to the second 90 degree distributor **42b**.

The function of the antenna feeding circuit according to the eighth embodiment of the present invention is explained below.

Eight band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h** disposed on the outer surface of the cylindrical body and the inner conductor 6 disposed on the inner surface of the cylindrical body 6 form eight micro-strips lines. Eight band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h** are grouped into four groups **5a, 5e; 5b, 5f; 5c, 5g; 5d, 5h**. The band conductors in each group is configured at opposite positions on the outer surface of the cylindrical body. The first group **5a, 5e** is connected to the first 180 degree distributor **2a**, the second group **5b, 5f** is connected to the second 180 degree distributor **2b**, the third group is connected to the third 180 degree distributor **2c** and the fourth group is connected to the fourth 180 degree distributor **2d**.

The other ends of each of the band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h** are connected to an element of the octifilar antenna 51, respectively.

Because each group of the band conductors **5a, 5c; 5b, 5f; 5c, 5g; 5d, 5h** are connected with the first to fourth 180 degree distributors **2a, 2b, 2c, 2d**, the inutile current induced in the inner surface of the inner conductor 6 can be cancelled out, in like manner as in the first embodiment.

Furthermore, the phase difference of the input signals from the first 90 degree distributor **42a** to the first and third 180 degree distributors **2a, 2c** is 90 degrees. Therefore, the phase difference between the current in the band conductor **5a** connected with the first 180 degree distributor **2a** and the current in the band conductor **5c** connected with the third 180 degree distributor **2c** is 90 degrees. Similarly, the phase difference between the input signals to the second and fourth 180 degree distributors **2b, 2d** from the second 90 degree distributor **42b** is 90 degrees. Therefore, the phase difference between the current in the band conductor **5b** connected with the second 180 degree distributor **2b** and the current in the band conductor **5d** connected with the fourth 180 degree distributor **2d** is 90 degrees.

Therefore, the phases of the currents in each two band conductors **5a, 5c, 5e, 5g; 5b, 5d, 5f, 5h** in the octifilar antenna 51 differ by 90 degrees in a cyclic manner. As a result, the octifilar antenna 51 functions as two sets of quadrifilar antenna comprising each two elements in the octifilar antenna.

According to the eighth embodiment, band conductors **5a, 5b, 5c, 5d, 5e, 5f, 5g, 5h** disposed on the outer surface of the cylindrical body 1 and the inner conductor 6 disposed on the whole of the inner surface of the cylindrical body 1 form micro-strips lines, and first to fourth 180 degree distributors **2a, 2b, 2c, 2d** supply electric power to each group of band conductors **5a, 5e; 5b, 5f; 5c, 5g; 5d, 5h** so that the phase difference between the currents in the band conductors in each group is 180 degrees. And the induced inutile currents at the inner surface of the inner conductor 6 can be cancelled out, because the inner conductor 6 is disposed on the whole of the inner surface of the cylindrical body 1. As a result, it is not necessary to use a balance-unbalance converter, i.e., a balun. And the structure of the antenna feeding circuit can be simplified. Furthermore, antenna feeding circuits for many antenna elements can be unified, when the outer surface of the cylindrical body are partitioned equidistantly.

ADVANTAGES OF THE PRESENT INVENTION

According to the present invention, the inner conductor and a pair of band conductors disposed on the outer surface of the cylindrical body form micro-strips lines. And inutile currents induced in the inner surface of the inner conductor can be cancelled out, because the inner conductor is disposed on the whole of inner surface of the cylindrical body, so that no balance-unbalanced converter, a balun, is necessary. That is to say, the structure of an antenna feeding circuit can be simplified.

In an embodiment of the present invention, an impedance matching circuit is disposed at the joint portion between the helical antenna and the antenna feeding circuit, therefore, electric power can be effectively supplied to the helical antenna so that the efficiency of the electromagnetic radiation can be improved.

In an embodiment of the present invention, a plurality of pairs of band conductors are disposed on the outer surface of

the cylindrical body, so that a plurality of antenna feeding circuits for multi-element helical antenna can be unified.

The antenna feeding circuit according to the present invention can be employed in feeding a helical antenna.

What is claimed is:

1. An antenna feeding circuit comprising:

a cylindrical body;

said cylindrical body having an inner and an outer surface;

an inner conductor disposed on the inner surface of the cylindrical body;

one or more pairs of electrically conductive bands disposed on the outer surface of the cylindrical body at a position symmetrical with respect to the axis of the cylindrical body so as to be parallel with the longitudinal direction of the cylindrical body, wherein each of electrically conductive bands has a first end and a second end for connecting an antenna element of a helical antenna;

one or more 180 degree distributors, connected to the first end of each of the band conductors, for supplying electric current to each of the band conductors through the first end, so that the phase difference between the electric currents in the band conductors is 180 degrees;

wherein each of the electrically conductive bands induce an inverse inutile current in the inner conductor.

2. An antenna feeding circuit according to claim 1, wherein an impedance matching circuit is connected to the band conductor.

3. An antenna feeding circuit according to claim 2, wherein the impedance matching circuit is a capacitor element.

4. An antenna feeding circuit according to claim 2, wherein the impedance matching circuit is a meander line.

5. An antenna feeding circuit according to claim 2, wherein the impedance matching circuit is a short stub.

6. An antenna feeding circuit according to claim 1, wherein the 180 degree distributor comprises:

a T-branching circuit having an input terminal and a pair of output terminals, which are T-branched from the input terminal; and

a delay line connected to either of the output terminals, the length of the delay line being equal to a half of the wavelength of a frequency in use.

7. An antenna feeding circuit according to claim 1, wherein the 180 degree distributor comprises:

a T-branching circuit comprising:

a first micro-strips line having an input terminal;

second and third micro-strips lines each having an output terminal, which are T-branched from the first micro-strips line;

a slot disposed on the substrate of the T-branching circuit so as to be perpendicular to the first micro-strips line, the length of the slot being substantially equal to half of the wavelength of a frequency in use;

wherein the first micro-strips line is grounded at a point on a side opposite to the input terminal of the first micro-strips line with respect to the slot;

the second micro-strips line is disposed on the same side as the input terminal of the first micro-strips line and is grounded at a point on the side opposite to the input terminal of the first micro-strips line with respect to the slot;

the third micro-strips line is disposed on the side opposite to the input terminal of the first micro-strips line and is grounded at a point on the same side as the input terminal of the first micro-strips line with respect to the slot.

8. An antenna feeding circuit according to claim 1, wherein said pair of electrically conductive bands is comprised of a first and second pair of electrically conductive bands;

said 180 degree distributor is comprised of a first 180 degree distributor for supplying electric current to the first pair of electrically conductive bands so that phase difference between the electric currents supplied to the first pair of electrically conductive bands is 180 degrees;

a second 180 degree distributor for supplying electric current to the second pair of electrically conductive bands so that phase difference between the electric currents supplied to the second pair of electrically conductive bands is 180 degrees;

said first and second 180 degree distributors are connected to a 90 degree distributor, which supplies electric current to said first and second 180 degree distributors so that the phase difference between the electric currents supplied to the first and second 180 degree distributors is 90 degrees.

9. An antenna feeding circuit according to claim 1, wherein said pair of electrically conductive bands is comprised of a first, second, third and fourth pair of electrically conductive bands; and

said 180 degree distributor is comprised of:

a first 180 degree distributor for supplying electric current to the first pair of electrically conductive bands so that the phase difference between the electric currents supplied to the first pair of electrically conductive bands is 180 degrees;

a second 180 degree distributor for supplying electric current to the second pair of electrically conductive bands so that the phase difference between the electric currents supplied to the second pair of electrically conductive bands is 180 degrees;

a third 180 degree distributor for supplying electric current to the third pair of electrically conductive bands so that the phase difference between the electric currents supplied to the third pair of electrically conductive bands is 180 degrees; and

a fourth 180 degree distributor for supplying electric current to the fourth pair of electrically conductive bands so that the phase difference between the electric currents supplied to the fourth pair of electrically conductive bands is 180 degrees; wherein:

said first and third 180 degree distributors are connected to a first 90 degree distributor, which supplies electric current to said first and third 180 degree distributors so that the phase difference between the electric currents supplied to the first and third 180 degree distributors is 90 degrees; and

said second and fourth 180 degree distributors are connected to a second 90 degree distributor, which supplies electric current to said second and fourth 180 degree distributors so that the phase difference between the electric currents supplied to the second and fourth 180 degree distributors is 90 degrees.

* * * * *

United States Patent

[11] 3,629,937

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[21] Appl. No. 798,832
[22] Filed Nov. 19, 1968
[45] Patented Dec. 28, 1971
[73] Assignee Chevron Research Company
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Original application Nov. 14, 1966, Ser. No. 593,967, now Patent No. 3,449,657, dated June 10, 1969. Divided and this application Nov. 19, 1968, Ser. No. 798,832

[54] **METHOD OF FORMING A HELICAL ANTENNA**
3 Claims, 16 Drawing Figs.

[52] U.S. Cl. .... 29/600, 29/624 R, 29/605 R, 343/719 R, 343/895 R
[51] Int. Cl. H01p 11/00
[50] Field of Search 29/600, 624, 601; 343/719, 895

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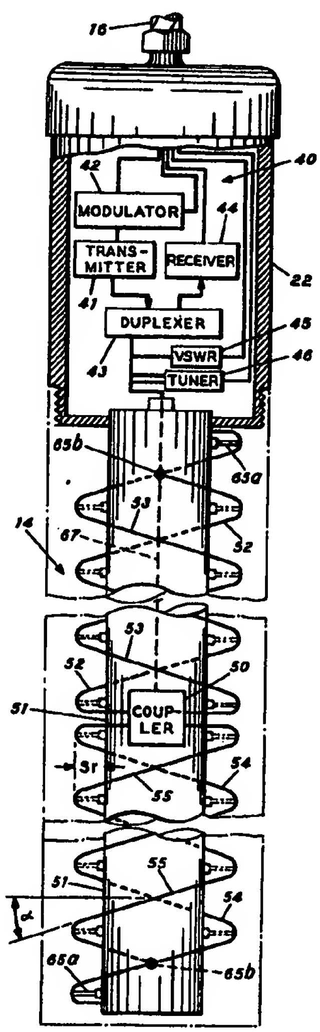
ABSTRACT: The method of making an antenna wherein pairs of conducting elements are helically disposed and supported around a central conducting element and longitudinally coupled with other conductive element pairs so arranged.



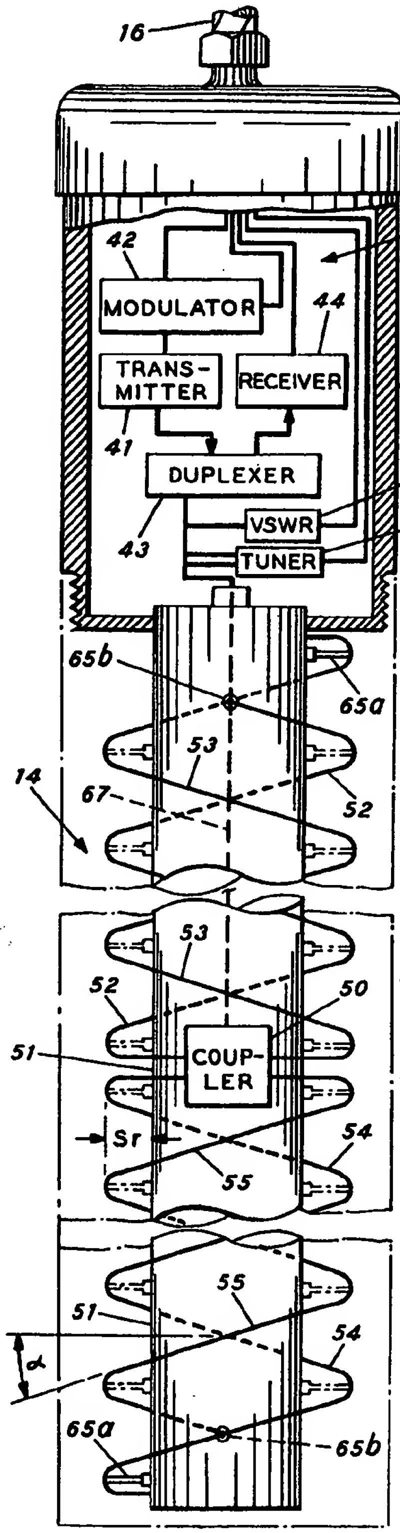


FIG.3

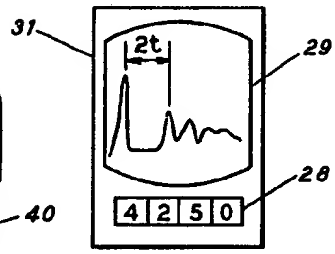


FIG.2a

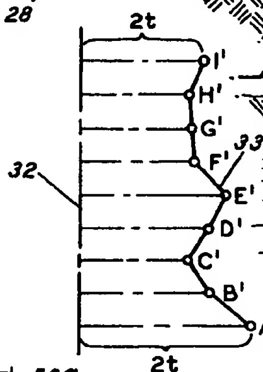


FIG.2b

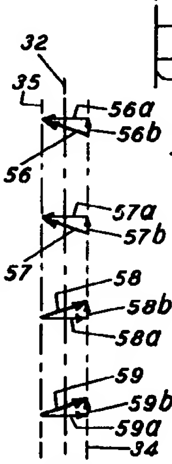


FIG.5

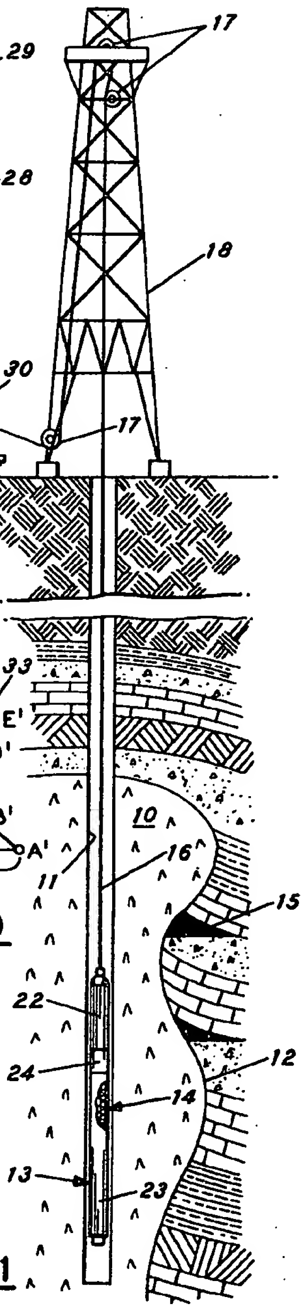


FIG.1

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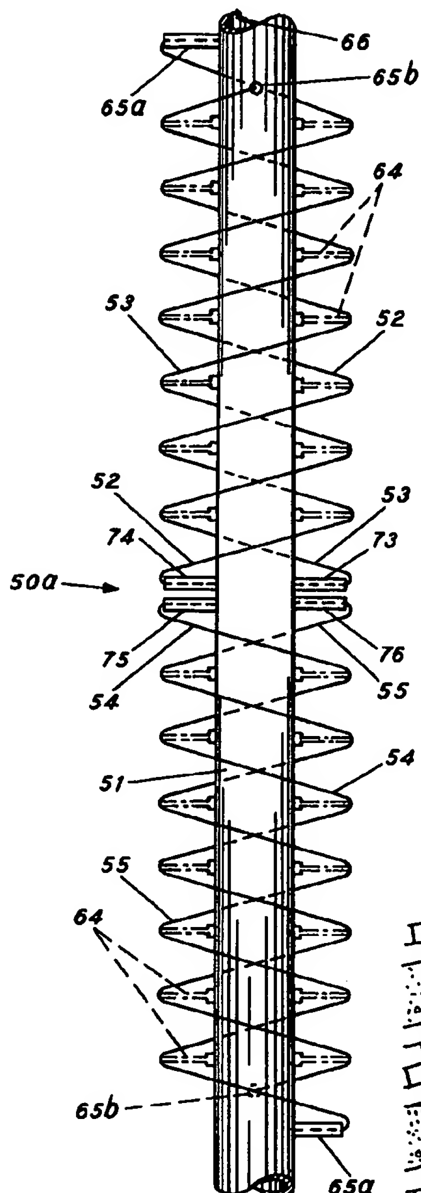

FIG. 7

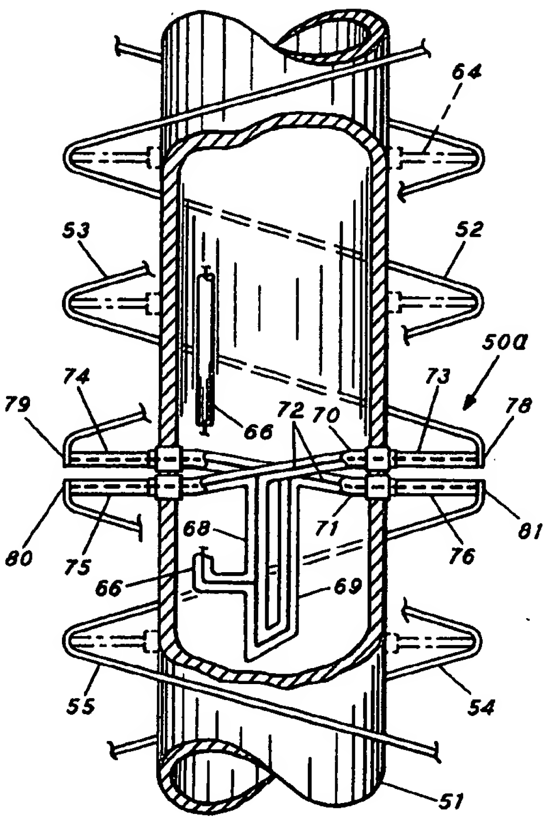

FIG. 8

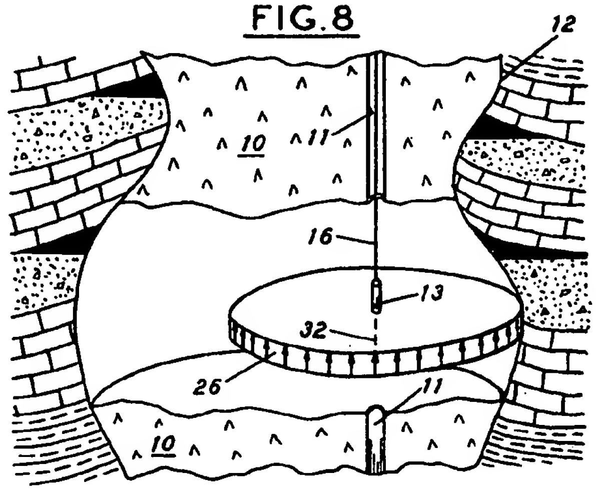

FIG. 4

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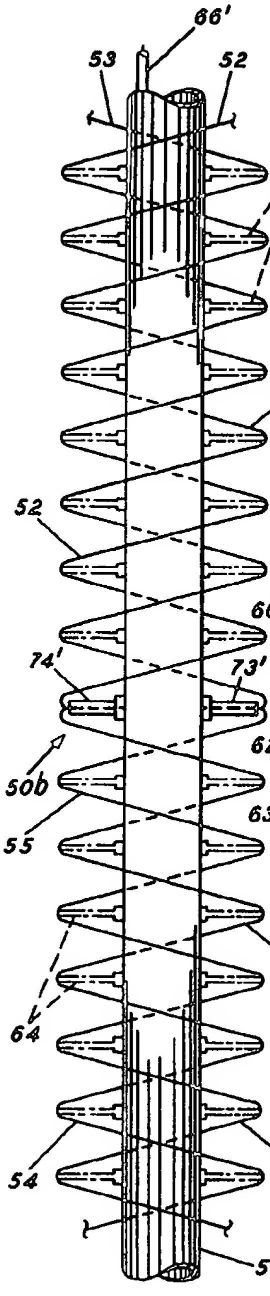

FIG. 9

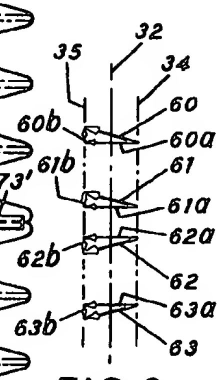

FIG. 6

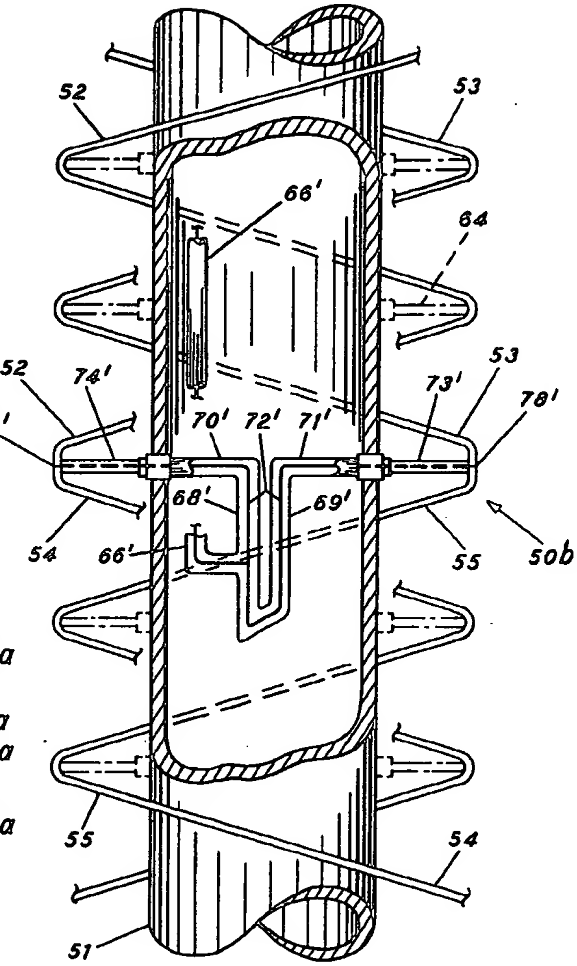

FIG. 10

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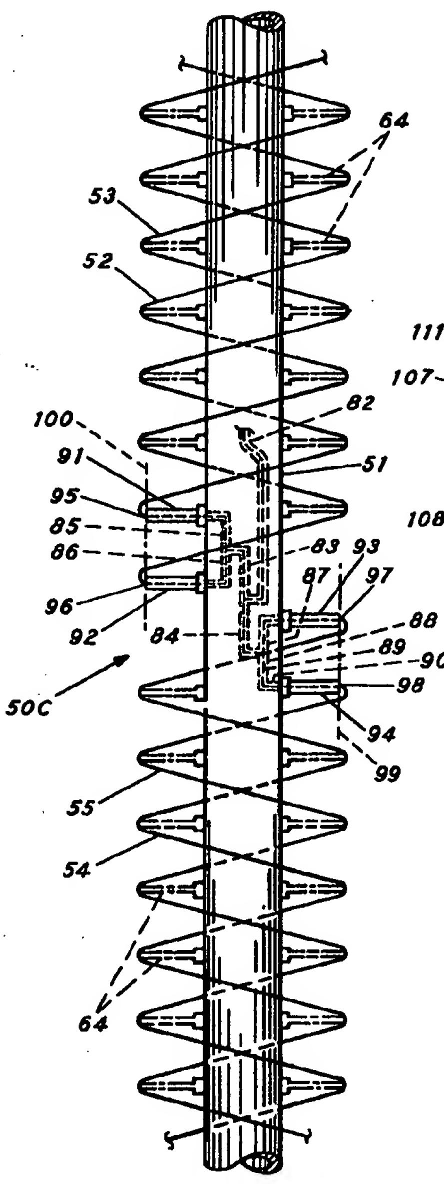

FIG.11

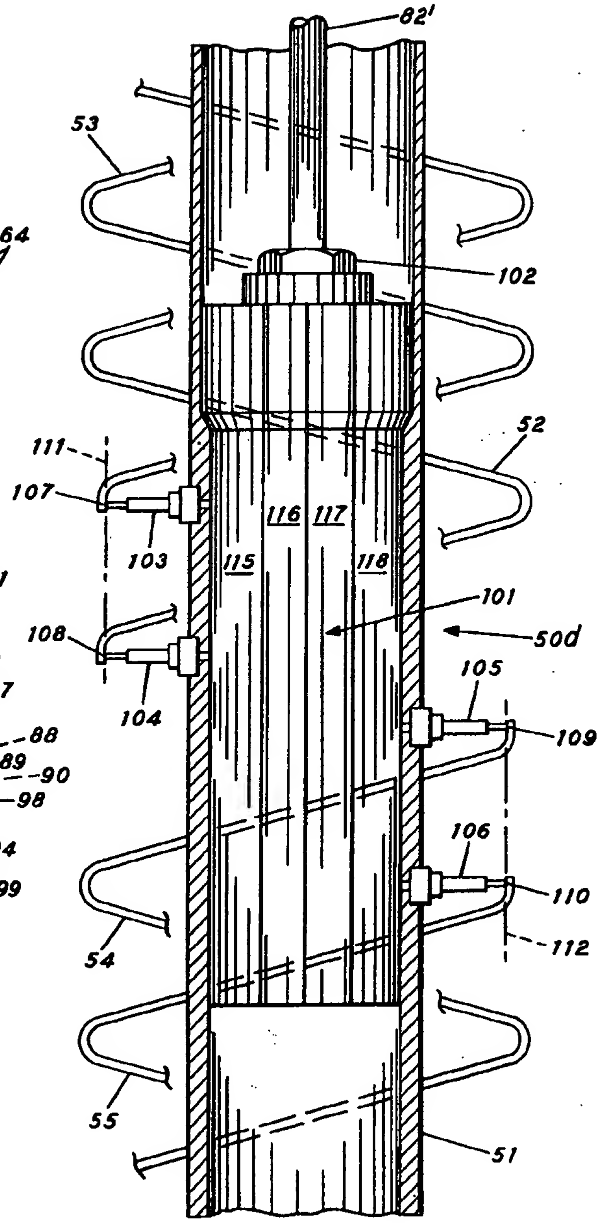

FIG.12

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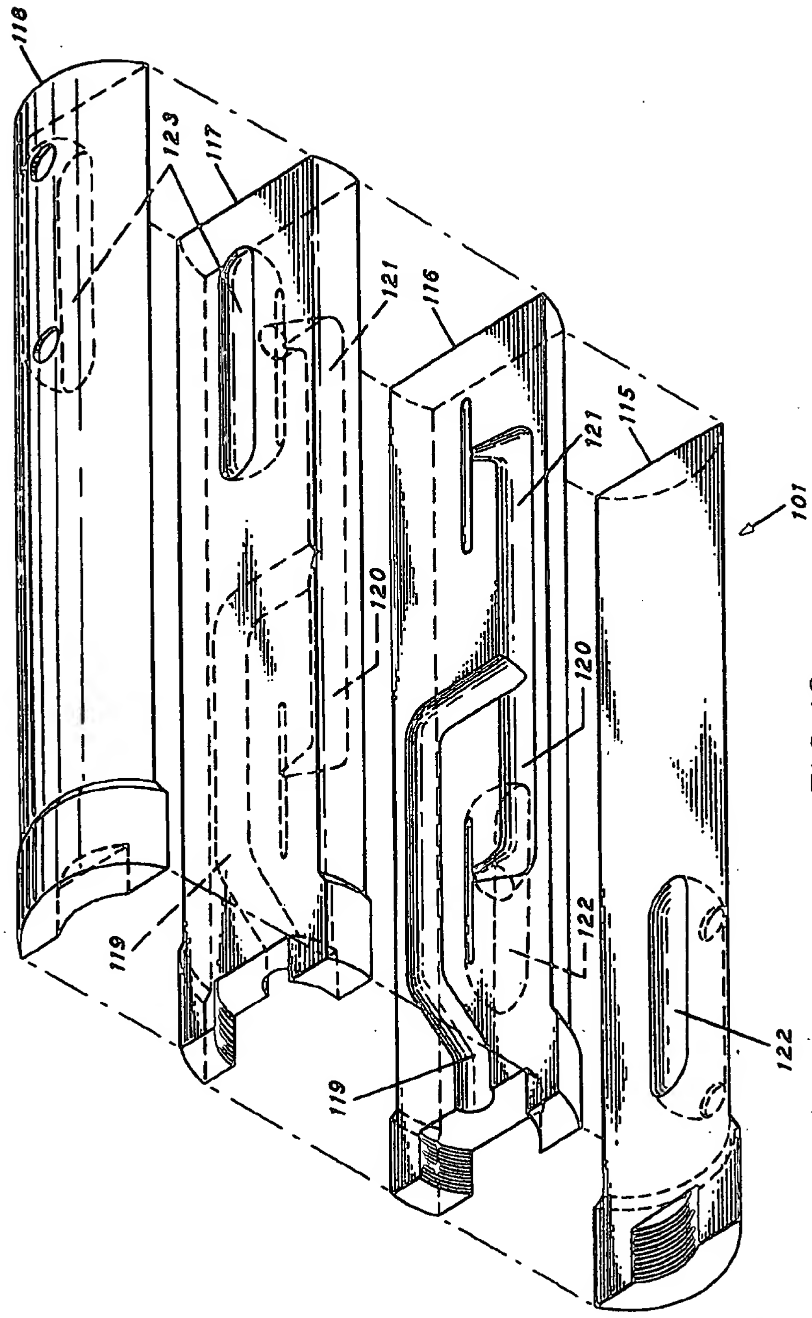

FIG.13

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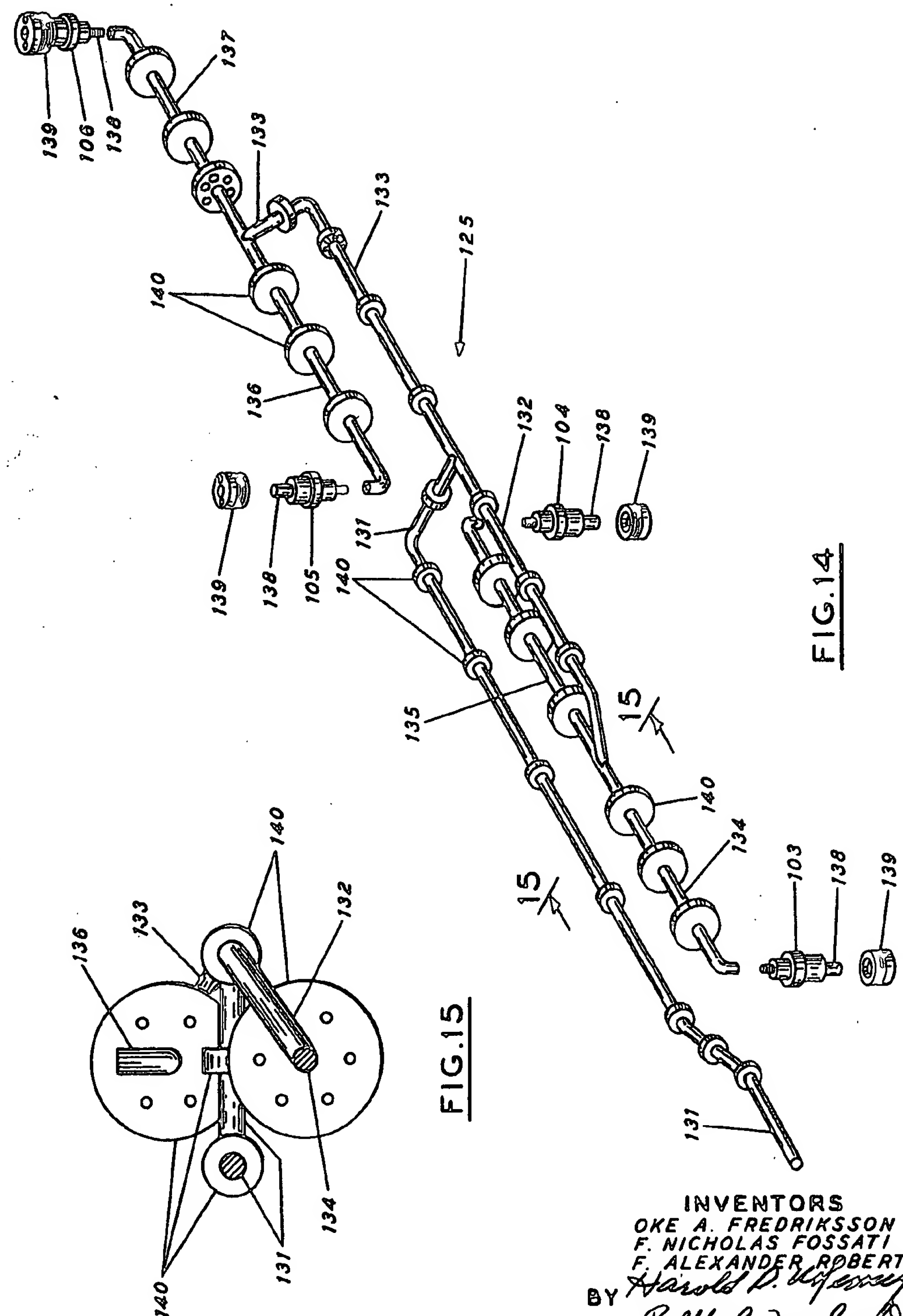

FIG.14

FIG.15

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METHOD OF FORMING A HELICAL ANTENNA

This is a division of Pat. application Ser. No. 593,967, filed Nov. 14, 1966 now Pat. No. 3,449,657, patented June 10, 1969.

This invention relates to the exploration for oil around a salt dome and to the mapping of the sides of the salt body from within a borehole penetrating the salt dome. More particularly, the invention relates to a method and apparatus for sequentially emitting electromagnetic energy from an antenna system within the well bore into the salt dome at a known elevation and receiving reflections of the launched energy from the sides of the dome. The transmission, reflection and reception of the energy are then related to time; and the time of travel of the emitted energy (from the source to the reflector and back) is related to horizontal distance and recorded in accordance with the depth of the antenna below the earth's surface to permit mapping of the interface of the salt dome.

A particular object of the present invention is a method and apparatus for improving the gain and efficiency of a helical antenna housed within a compactly constructed sonde traversing the borehole penetrating the salt dome. The improved gain and efficiency of the antenna are at least partially derived from the design of the antenna system and related energization equipment to provide the transfer of radiation through the dome. The field radiated by the antenna of the present invention is omnidirectional in azimuth to permit uniform distribution of the radiated energy to all points in circles concentric of the antenna. In the elevational direction—i.e., in planes normal to the surface of the earth—the field is highly directional.

The art to which the present invention relates is described in a copending application of W. T. Holser, R. R. Unterberger and S. B. Jones, Ser. No. 253,339, filed Jan. 23, 1963, for "Method of Mapping a Salt Dome at Depth by Measuring the Travel Time of Electromagnetic Energy Emitted from a Borehole Drilled Within the Salt Dome." In that application, a method is described for mapping the distance to the flanks of a salt dome from within a well bore penetrating the dome.

It is known that an antenna may be formed by winding a conductor helically about a conductive supporting mast and that such an antenna may be energized to propagate energy in an equiazimuthal pattern relative to the longitudinal axis of the mast. Such an antenna, known as a helical antenna, is disclosed in U.S. Pat. Nos. 2,985,878, L. O. Krouse et al., issued May 23, 1961, for "Wound Antenna with Conductive Support," and 2,953,786, L. O. Krouse, issued Sept. 20, 1960, for "Antenna for Polarized Propagation."

In a helical antenna of the type described in the prior art patents, one conductor of the pair of conductors forming the transmission line feeding the antenna is connected to the supporting mast of the antenna and the other conductor is wound helically with a prescribed pitch and turn length about and supported on the mast. The mast is formed of conductive material, and usually a number of turns are wound about the mast. The wound element is then terminated at a distance from the feed end. If the axial length of the antenna is short, the characteristic impedance of this system may be maintained by impedance elements at the terminal ends of the antenna.

A concern of the present application is a helical antenna system used to accomplish emission of electromagnetic radiation—directional in elevation but omnidirectional in azimuth—within the environment of a borehole drilled thousands of feet into a salt dome. The radiated electromagnetic energy is transmitted through the dome and then reflected from the electromagnetic discontinuity formed at the flanks of the dome spaced from the borehole. The travel time of the energy to the reflector and back is measured, and the distance from the antenna to the near salt flank is approximated by computation from the known velocity of energy transmission through the salt to permit a partial mapping of the dome.

Several problems become evident in adapting conventionally formed helical antennas for use in the above method of logging of salt domes:

1. **The conventional helical antenna within an exploration sonde may be too large for the standard-sized boreholes drilled into the salt dome, say from 5 to 12 inches in diameter;**
2. Where the antenna size is reduced to form a more compact design, gain and directivity characteristics of the antenna may not be adequate to map large-sized domes, especially where severe downhole environmental conditions are encountered—e.g., high pressure, high temperature, etc.;
3. The beam width (elevational spread) of the emitted electromagnetic radiation may be too wide. Accordingly, it may be difficult to obtain, among other things, high resolution of the returning signals (echoes) from the near wall of the dome; and
4. The support of the antenna within the sonde may be inadequate to withstand usual shocks, static and bending loads encountered in conventional logging practice.

In accordance with the present invention, the effective area of radiation of the helical antenna—and, hence, antenna gain—is increased by forming the antenna-radiating elements of a multiplicity of coextensive pairs of interwound helical conductors extending along the well bore, say for 15 feet. The radiation intensity per unit length of antenna is increased without requiring a corresponding increase in the required all over diameter of the antenna by employing dual propagating conductors along the antenna. A broadside pattern of radiation is accomplished in the antenna of the present invention by including a central conducting cylinder concentric within and coextensive of the helical conductors. Radiation of minimum beam width is accomplished by establishing the turn length of the helical conductors as an integral number of operating wavelengths of the energy as it is transmitted within the salt dome.

The antenna is a part of a logging tool, and a source of electromagnetic energy may be housed in the upper end of the logging tool and connected to the antenna by an appropriately constructed input coupler ruggedly supported within the central cylinder. Energy is emitted from the source, progresses through the coupler and thence between the helices, conductors and central cylinders so as to radiate in elevational planes normal to the well bore. The electrical circuit of the antenna is closed by interconnecting the input coupler with both the central cylinder and the helical conductors.

Preferably, but not necessarily, the ends of the helical conductors are terminated in contact with the central cylinder remote from the input coupler and at appropriately spaced locations so as to provide nonreflective termination of the energy input to the antenna. The terminal locations are preferably spaced apart a circumferential length measured along the path of one of the pairs of helical conductors equal to $N\lambda_f/4$, where N is any odd integer and λ_f is the formation wavelength. The voltage standing wave ratio (VSWR) of the antenna is accordingly decreased with corresponding improvements in antenna performance—for example, gain and directivity.

Further in accordance with the present invention, the helical conductors may be fed in phase at the midpoint of the conducting cylinder in such a manner to provide a vertically polarized radiation field without interconnecting the antenna with a phase shifter at the input coupler as required by conventional vertically polarized helical antenna systems. In the present invention, the input coupler may include, in a preferred form, a coaxial distributor manifold connected through a flexible coaxial line to the source of the electromagnetic energy. The distribution manifold is cylindrical and is ruggedly mounted within the conducting cylinder. Four axially spaced output terminals protrude radially from the manifold through the central cylinder and into contact with the respective ends of the pairs of helical conductors at selected coupling points about the central cylinder. The axial distance between the output terminals of the manifold is related to the turn length of the conductors in accordance with $N\lambda_f/2 \sin \alpha$ where N is any odd integer, λ_f is the formation wavelength, and α is the pitch angle of the pairs of conductors. Employing

this spacing, the input energy to the pairs of conductors is properly phased to increase the effective radiation per unit length of the antenna.

Further objects and advantages of the invention will become more apparent from the following detailed description taken in conjunction with the accompanying drawings which form a part of this specification.

In the drawings:

FIG. 1 is a partial section of an earth formation including a salt dome penetrated by a borehole and illustrates a logging sonde and other apparatus for energizing and transporting the sonde in logging the salt dome;

FIG. 2a is a representation of the face of a recording instrument displaying the information to be derived from the logging sonde of FIG. 1;

FIG. 2b is a two-dimensional plot of the near flank of the salt dome of FIG. 1 as a function of depth;

FIG. 3 is an elevational view of the logging sonde of FIG. 1 partially cut away to illustrate a helical antenna adapted to radiate electromagnetic energy for logging the distance to the flank of the dome of FIG. 1;

FIG. 4 is a partial perspective section of the dome of FIG. 1 illustrating the disclike radiation pattern of equiazimuthal, vertically polarized, energy from the helical antenna of FIG. 3 to the flanks of the salt dome;

FIG. 5 is a plot of electric field components of the emitted energy along sections of the helical antenna of the present invention illustrating how the components are resolved to generate vertically polarized electromagnetic radiation;

FIG. 6 is a second plot of the electric field components along the antenna to illustrate the generation of horizontally polarized radiation;

FIGS. 7 and 8 are elevational views of the helical antenna of FIG. 3 in which the antenna is adapted to generate vertically polarized electromagnetic radiation; FIG. 8 being enlarged and partially cut away to illustrate a coupler at the interior of the antenna;

FIGS. 9 and 10 are elevational views of a second embodiment of the helical antenna of FIG. 3 adapted to radiate horizontally polarized electromagnetic radiation; FIG. 10 being enlarged and partially cut away to illustrate energization means at the antenna interior;

FIG. 11 is an elevational view of another embodiment of the helical antenna of the present invention partially cut away to illustrate the antenna coupler;

FIG. 12 is an elevational view of still another embodiment of the helical antenna of the present invention;

FIG. 13 is an exploded view of the housing of the coupler of FIG. 12;

FIG. 14 is an isometric view of the inner conductor sections of the coupler of FIG. 12; and

FIG. 15 is a sectional view taken along line 15—15 of FIG. 14.

Referring now to FIG. 1, a section of a salt dome 10 is shown penetrated by a borehole 11 offset from the center of the dome so as to be adjacent to one of its flanks. In order to accurately define the near sidewall of the dome 10 through controlled emission and reception of electromagnetic energy, an exploration sonde 13 incorporating an electromagnetic helical antenna, generally indicated at 14, is transported along the borehole so as to placed adjacent to differing horizontal sections of the dome. The purpose of mapping the near side of the salt dome-sedimentary interface 12 is to identify those areas where oil deposits 15 are most likely to be found adjacent the sidewall of the dome.

To provide movement of the sonde 13 through the borehole 11, a logging cable 16 is connected through sheaves 17 on derrick 18 to cable drum 19. Motor 20 powers drum 19 on hoist truck 21 to raise and lower the sonde.

As the borehole 11 may be filled with a dense drilling fluid to prevent intrusion of the earth formation into the borehole, the sonde 13 must be fluidtight at the mating joints of the upper housing 22 with lower housing 23 supporting the helical antenna 14. The upper housing 22 is connected to the lower housing 23 by union collar 24 as indicated.

Located within truck 21 is a console 25 containing a power source and associated coupling circuitry suitable for feeding timing signals along logging cable 16 to the sonde 13, as well as indicators for the source and coupling circuitry. Console 25 may also include surface recording equipment including at least three indicators: one for impedance match, indicator 27; another for depth, indicator 28; and another for distance, indicator 29. The impedance match displayed on indicator 27 relates to the power transfer between the helical antenna 14 and coupling circuitry within the sonde 13 as a function of their respective impedances, and the matching is performed downhole during operation of the antenna. Depth indicator 28 shows the mapping depth of the antenna in the borehole 11 and is measured by pulley 30. The distance from the borehole to the sidewall of the near side of the salt dome at each mapping depth is a function of the time between transmission and reception of the electromagnetic energy by the antenna and is displayed on indicator 29. The information on the indicator 29 and the depth indicator 28 can be simultaneously recorded using a camera to produce a photographic plate of the type indicated at 31 in FIG. 2a. Plate 31 indicates the two-way travel time (2T) for emitted signals, and a series of these photographs may be reduced to a two-dimensional plot, such as shown in FIG. 2b, in which the location of the near wall of the salt body relative to antenna axis 32 is represented by line 33 connecting mapped points A', B', C', D', E' etc.

Reference should now be had to FIG. 3. This figure illustrates the energization section 40 for helical antenna 14 for utilizing timing signals fed from control console 25. As indicated, the energization section 40 includes transmitter 41 which is periodically energized through modulator (pulser) 42 so as to generate electromagnetic pulses of high power and relatively short duration. Since helical antenna 14 is used for both transmitting and receiving, a switching arrangement 43, called a duplexer, is connected across transmitter 41 and receiver 44 as indicated. As well understood, the duplexer 43 isolates the sensitive receiver 44 from the transmitter when energy is fed to the antenna and then connects the antenna to the receiver 44 in the interval between pulses where the reflected energy is to be received.

VSWR coupler 45 is connected so as to sense the energy transmitted between the duplexer 43 and the antenna 14. The coupler 45 samples the energy in the connecting transmission line to indicate the power transferred to the antenna as a function of the relative impedances of the antenna and the energization section 40. An antenna system is composed of a number of component parts, and associated with these components will be lengths of low-loss lines that are likely to be electrically "long" although physically "short."

In regard to matching the antenna 14 and energization sections 40 to the transmission line between these components, adjustments in the length of the line may be achieved in the present invention through a stub tuner 46 connected in parallel with VSWR coupler 45. Operation of tuner 46 is adjustably controlled by circuitry within the console 25 as the console operator monitors the response of VSWR coupler 45 at indicator 27 (FIG. 1).

During actual operation of the antenna system, energy is symmetrically coupled at a midportion of the antenna 14 by coupler 50 connected in series with energization section 40. During such operation, helical antenna 14 fundamentally may be thought of as a transmission line directing the transmission of first and second pairs of electromagnetic waves beginning at coupler 50 and helically winding in opposite axial directions to the remote ends of the antenna. The first pair of waves propagate in helical paths between a first pair of coextensive helical conductors 52 and 53 and central cylinder 51 interior of the helical conductors as indicated in FIG. 3. The second pair of waves helically propagates in a similar manner but in an opposite axial direction to that of the first pair of waves between a second pair of coextensive helical conductors 54

and 55 also coextensive with the central conductor 51. The helical conductors 52, 53 and 54, 55 are radially spaced from the central conductor 51 a constant radial distance (S_r) and helically wind at a constant pitch angle (α) about the central conductor 51. Across a midportion of the central conductor 51, the adjacently located ends of the helical conductors, termed "near" ends, are connected to the coupler 50 as shown.

In analyzing the pairs of electromagnetic waves, several characteristics become evident. For example, as each pair of waves propagates along the antenna, their phases remain identical although varying periodically with distance from the coupler 50; however, their amplitudes decay as radiation from the antenna occurs. Each wave thus contributes to the intensity of the resultant radiation field.

As previously indicated, the helical conductors 52, 53 and 54, 55 and the central cylinder 51 are designed to direct the transmission of electromagnetic energy along helical paths about the cylindrical conductor 51. Accordingly, as the waves are composed of electric and magnetic fields that adjust their configurations to satisfy Maxwell's boundary equations, the physical dimensions of the pairs of helical conductors 52, 53 and 54, 55 and central cylinder 51 are of importance. For example, the circumferential turn length of the helical conductors must be designed to be greater than the radial spacing (S_r) between the helical conductors and the central cylinder 51. Accordingly, the coupling of the electromagnetic waves between adjacent turns will be greater than that between the helical conductors and the central cylinder. Furthermore, circumferential turn length of the helical conductors should also be a common value along the full extent of the antenna. Each turn length is preferably made equal to a value related to the phase of the adjacent pairs of electromagnetic waves so that they are correctly phased for interaction in both the transverse and axial directions along the length of the antenna. In this regard, a preferred common turn length of $M\lambda_f$, where M is any integer (preferably one) and λ_f is the operating wavelength of electromagnetic energy in the salt dome, is preferred.

Although the physical dimensions of the pairs of helical conductors are preferably equal, as previously mentioned, it may be desirable on some applications to deviate from the preferred construction. For example, the first pair of helical conductors 52, 53 may have a different turn-to-turn spacing than the second pair of helical conductors 54, 55 in order to generate circularly polarized radiation. Additionally, the use of the antenna in deep, narrow boreholes is seen to be aided by the fact that, even if the radial spacing (S_r) should be reduced (thereby reducing the radiation per unit length of the antenna), the antenna is still adequate for most logging applications.

The first and second pairs of helical conductors 52, 53 and 54, 55 are constructed to be symmetrical on either side of a reference plane perpendicular to the axis of the central cylinder 51. The reference plane passes through the midpoint of coupler 50. Such symmetry permits an interaction between the first and second pairs of electromagnetic waves propagated in opposed axial directions to establish controlled polarization of the resultant radiated field.

The polarization of the radiated energy relates to the direction of the electric field components of the radiated field in the principal direction of propagation. As illustrated in FIG. 4, the radiated energy from a broadside radiating the helical antenna within sonde 13 is in the form of an expanding solid of revolution having uniform radiation in planes traverse to the axis 32 of the antenna. A small section of the energy is called a wave front, generally indicated at 26. The wave front 26 is located perpendicular to the direction of travel of the energy as the energy propagates from the borehole 11 in radial directions through the salt dome 10. The wave front ultimately encounters the interface 12 of the salt body and the surrounding formation, and a portion of the energy is reflected. The electric field components at the wave front may be disposed in a linear alignment in one of two directions: either perpendicular to the antenna axis 32 or parallel to it.

When the electric field component is normal to the axis 32 of the antenna, the distribution is termed horizontally polarized radiation. When the electric field component is parallel to the axis 32 of the antenna, the distribution is called vertically polarized radiation. When the electric field components disposed on the wave front have resultant vectors in both the vertical and horizontal directions, the distribution is called circularly polarized radiation.

In general, the electric field component of the pairs of electromagnetic waves along the antenna is parallel to the incremental length of the helical conductor from which it radiates. Furthermore, each electric field component has an amplitude and direction equal to the instantaneous signal current flowing in the incremental conductor lengths. These orientations are maintained as the electromagnetic energy radiates from the antenna. Where the conductor lengths make an angle with the principal direction of propagation, there are thus provided electric field components that make an angle with the axis 32 of the antenna that is the same as the pitch angle (α) of the pairs of helical conductors 52, 53 and 54, 55.

Furthermore, the electric field components of the pairs of electromagnetic waves on the antenna also have the property of interacting with each other. They are vector qualities which are governed by the principles of vector algebra. Accordingly, the pairs of electromagnetic waves propagating in opposed axial directions on the antenna may be adapted to interact as a function of their position along the antenna, as measured in opposed but equal axial distances from the center of the antenna so as to provide linear polarization of the resulting radiation.

For example, to provide vertical polarized radiation, the signal currents on the transversely aligned portions of each pair of helical conductors, say helical conductors 52, 53, must be the same magnitude and of equal polarity relative to each other but, most importantly, be of opposite polarity to the symmetrically located signal currents on the oppositely extending pair of helical conductors (for this example, helical conductors 54, 55) at equal distances from the center of the antenna as measured in the same azimuth direction from the longitudinal axis of the antenna. As indicated in FIG. 5, when these conditions exist, electric field components represented by arrows 56, 57, 58 and 59 are generated along the antenna. These arrows represent the instantaneous electric fields found in axially spaced sections of the helical conductors defined by an imaginary geometrical figure having a wedge-shaped cross section, one corner of which lying on antenna axis 32 and two remaining corners lying on parallel lines 34 and 35 radially spaced from and parallel with the antenna axis 32. As the electric field components of the pairs of waves are symmetrical about the midpoint of the antenna, they may be resolved into reinforced vertical field vectors *56b*, *57b*, *58b* and *59b* radiating from the antenna and cancelable horizontally aligned electric field vectors *56a*, *57a*, *58a* and *59a*. Accordingly, the first pair of waves interacts with the second pair of waves to generate vertically polarized electromagnetic radiation.

To provide horizontally polarized radiation, the field currents on transversely aligned portions of each pair of helical conductors 52, 53 and 54, 55 must also be of equal magnitude and of opposite polarity as before but, most importantly, must be of the same polarity as respective signal currents at a corresponding symmetrical plane on the other pair of helical conductors. As indicated in FIG. 6, when these conditions exist, electric field components represented by arrows 60, 61, 62 and 63 are generated along the antenna in a region defined by antenna axis 32 and parallel lines 34 and 35. These components are resolvable, as previously explained, into reinforced horizontal electric field vectors *60a*, *61a*, *62a* and *63a* and cancelable vertically directed field vectors *60b*, *61b*, *62b* and *63b*. Accordingly, the first and second pairs of waves axially propagating along the antenna away from the midpoint interact to generate horizontally polarized radiation.

It is known that when an antenna is not terminated in its characteristic impedance, there will be two traveling waves on the antenna, one carrying power toward the terminating end

"incident wave" and the other carrying power away from the end "reflected wave." The net power radiated from the antenna is the difference in the power contained in the two waves. Furthermore, as the waves propagate, the antenna absorbs power from each wave and thusly causes a corresponding reduction in gain of the antenna.

As indicated in FIG. 3, to prevent reflective waves from each end of the antenna of the present invention, terminals 65a and 65b are formed of an electrically conductive material; and the terminals 65a and 65b are adapted to be spaced apart along central cylinder 51 in contact with both the pairs of helical conductors 52, 53, and 54, 55 and the central cylinder 51. As incident pairs of waves traveling down the antenna are reflected in part at any discontinuity where they encounter an impedance other than the impedance of the line on which they travel, the magnitude and phase of the reflected waves, say from posts 65a and 65b, will depend upon the amplitude and phase of the reflecting impedance. If a common impedance load is used to terminate both helical conductors, the relative amplitude and phase of the reflected waves will be the same. The resultant reflected waves of each pair of waves will be maximum when the reflected waves add in phase and minimum where they are opposed in phase. Thus, if the length between posts 65a and 65b at each end of the antenna is equal to $N\lambda_r/4$, where N is any odd integer and λ_r is the operating wavelength of energy in the salt body, each pair of reflected waves will have a relative phase difference of $\lambda_r/2$ or its equivalent as measured in common transverse planes normal to the axis of the antenna. (Wavelength is defined as one cycle of variation of the energy in the principal direction of propagation.) In the above embodiment, the distance between terminals 65a and 65b is measured along the longer of each pair of helical conductors between the transverse plane through the terminals; i.e., along helical conductors 53 and 54. Since the relative strength of the reflected waves is the same, the pair of reflected waves, due to connecting the ends of each pair of helical conductors 52, 53 or 54, 55 to the central cylinder 51, are thus completely canceled, minimizing the voltage standing wave ratio (VSWR) of the antenna. The voltage standing wave ratio (VSWR) is defined as the ratio of the maximum to the minimum field strength of the incident and reflected waves as the position along the line is varied through a distance of at least a half wavelength.

With regard to the operating frequency of the system, loss-tangent measurements on samples of halide taken from salt domes indicate rather low loss for energies in the frequency range from 10^6 to 10^{10} cycles per second. Above this range, the losses become excessive; below this range, the resolution of returning echoes becomes difficult. Inasmuch as operating frequency is directly related to the operating wavelength, a preferred range of operating wavelength for the energy used in conjunction with the antenna of the present invention is thus from 1.24×10^{-2} to 1.24×10^{2} meters in length or integral equivalents thereof.

In FIGS. 7 and 8, a coupler embodiment, generally indicated at 50a, feeds energy to the helical antenna of the present invention to generate vertically polarized electromagnetic radiation. As the coupler 50a has the effect of combining the characteristic impedance of the helical conductors 52, 53 and 54, 55 in parallel, the "match" of the helical conductors to the input transmission line 66 is thus facilitated.

As shown in FIG. 7, the energy is fed from input line 66 to coupler 50a and then is connected to the antenna between the pairs of helical conductors 52, 53 and 54, 55 and central cylinder 51. As the helical conductors are insulated from the central cylinder, as by posts 64, voltages and currents are established along the helical conductors and the central cylinder for generating first and second pairs of axially propagating electromagnetic waves as previously mentioned. The resulting pairs of electromagnetic waves propagate in opposed axial directions from input coupling posts 73, 74, 75 and 76 of the coupler 50a toward terminals 65a and 65b at the ends of the antenna.

As shown in FIG. 8, coupler 50a also includes a series of split conductors forming extensions of the input line 66. In particular, coaxial line sections 68 and 69 are connected in parallel to the input line 66 and terminate in contact with coaxial extensions 70 and 71, respectively, at a plane near the midpoint of the antenna. The extensions 70 and 71 are seen to be perpendicularly oriented relative to the line sections 68 and 69 and connect via inner conductor 72 to the coupling posts 73, 74, 75 and 76. The coupling posts in turn connect to pairs of helical conductors 52, 53 and 54, 55 at coupling points located exterior of the central cylinder 51. These coupling points are generally indicated at 78, 79, 80 and 81. Viewed from a side of the antenna (FIG. 8), the coupling points define an imaginary parallelogram having parallel opposite sides. The two diagonally located coupling points 78 and 80 connect to the inner conductor of extension 70 and form one set of coupling points. The other two diagonal coupling points 79 and 81 connect to the inner conductor of extension 71 and form a second set of coupling points. As coupling posts 73, 74, 75 and 76 have insulated sidewalls, the coupler circuit is closed at the bases of the coupling posts by connecting the outer conductor of the extensions 70 and 71 to the central cylinder 51.

Energizing the antenna conductors with signal currents of the correct polarity depends upon the line length of section 68 relative to section 69. Accordingly, if section 68 is constructed so that its length is exceeded by the length of section 69, say by a distance equal to $\lambda_r/2$, where λ_r is the operating wavelength of energy in the salt body as previously defined, correct feed conditions exist. Each pair of helical conductors 52, 53 and 54, 55 has one conductor fed from the coupling points 78, 80 and one fed from the coupling points 79, 81 so that the energization on the conductors of each pair is 180° out of phase. It should be noted that, while along successive transverse sections of the helical conductors the polarity of the signal current undergoes periodical change, the relative polarity along the antenna remains 180° out of phase to generate the desired vertically polarized energy from the antenna.

However, the adjacent—axially spaced—coupling points 79, 80 and 78, 81, being of opposite polarity, must be sufficiently insulated to prevent breakdown during operation of the antenna. In this regard, an air-dielectric may be suitable as an insulator in low-power antenna applications although dielectric strength of the medium may have to be increased for high-power operations, as by a separate ceramic insulating member between the adjacent coupling points 79, 80 and 78, 81.

In FIGS. 9 and 10, a second embodiment of the coupler of the present invention is generally indicated at 50b for properly energizing the antenna to generate horizontally polarized electromagnetic radiation. As shown in FIG. 9, the energy is fed from input line 66' to coupler 50b and then is connected to the antenna between the pairs of helical conductors 52, 53 and 54, 55 and central cylinder 51. As the helical conductors are insulated from the central cylinder by posts 64, voltages and currents are established along the helical conductors and the central cylinder for generating the pairs of axially propagating electromagnetic waves previously mentioned. The resulting pairs of electromagnetic waves propagate in opposed axial directions from input coupling posts 73' and 74' of the coupler 50b toward the ends of the antenna.

As shown in FIG. 10, the coupler 50b also includes a series of conductors forming the extensions of the input line 66' similar to the coupler 50a of FIGS. 7 and 8. As indicated, sections 68' and 69' are connected in parallel to the input line 66' and terminate at a plane near the midpoint of the antenna in contact with coaxial extensions 70' and 71'. The extensions 70' and 71' connect via common inner conductor 72' to the coupling posts 73' and 74'. The posts in turn connect to the first and second pairs of helical conductors at two diametrically opposed coupling points indicated at 78' and 79'. Each coupling point is exterior of the central cylinder 51. As

coupling posts 73' and 74' have insulated sidewalls, the coupler circuit is closed by connecting the outer conductor of the coupler to the central cylinder 51 at the bases of the coupling posts. To establish correct energization conditions, section 68' is constructed so that its length exceeds the length of 69' by a distance equal to $\lambda_t/2$ as previously defined. One conductor of each pair of coextensive helical conductors 52, 53 or 54, 55 thus is energized at a common coupling point 78' or 79' with the same phased signal, but each pair of helical conductors is energized with complementary polarized signal currents at the coupling points 78' and 79'. As these signals periodically vary along the antenna, the first and second pairs of electromagnetic waves propagate from the points 78' and 79' toward the remote ends of the antenna interacting, as previously explained, to generate horizontally polarized radiation.

In FIG. 11, a third embodiment of coupler is generally indicated at 50c for properly energizing the antenna to generate vertically polarized electromagnetic radiation. The coupler 50c preferably includes a series of coaxial line sections indicated at 82, 83, 84, 85, 86, 87 and 88. These sections are geometrically arranged and form a single input section 82 to a series of output sections 85, 86, 87 and 88 through intermediate sections 83 and 84. As indicated, the sections have a common inner conductor 89 and a common outer conductor 90. The inner conductor 89 is connected to helical conductors 52, 53, 54 and 55 by coupling posts 91, 92, 93 and 94 at the exterior of the central cylindrical conductor 51. As the coupling posts 91, 92, 93 and 94 have insulated sidewalls, the outer conductor 90 of the output sections 85, 86, 87 and 88 may all be connected to central cylinder 51 at the bases of the coupling posts.

As indicated, the coupling points 95, 96, 97 and 98 are not transversely aligned, as is the case in the coupler 50a of FIGS. 7 and 8, but instead are connected to the adjacent ends of the helical conductors 52, 53, 54 and 55 at coupling points 95, 96, 97 and 98 axially spaced along central cylinder 51. The coupling points define two sets of points. Each set of points 95, 96 or 97, 98 is azimuthally spaced so that the individual coupling points are aligned along a line 99 or 100 parallel to the longitudinal axis of the central cylinder 51, but each set is also diametrically located with respect to the other set of coupling points. Preferably, where the turn length of the helical conductors 52, 53, 54 and 55 is equal to an integral full operating wavelength, each of the more remote coupling points—coupling points 95 or 98—is spaced a common distance from the mating coupling points 96 or 97. When measured along one of the helical conductors, the distance is equal to one-half turn length or its integral equivalent of the measuring conductor. One of each pair of the coextensive helical conductors is thus shortened relative to the other helical conductor over the longitudinal length of the coupler 50c. An equivalent expression for the spacing of the coupling points, when measured along lines 99 or 100 and between transverse planes through the coupling points, is $M\lambda_t/2 \sin \alpha$, where M is any odd integer, λ_t is the operating wavelength as previously defined, and α is the pitch angle of the helical conductors.

In FIGS. 12, 13, 14 and 15, a fourth embodiment of the coupler is generally indicated at 50d for use in vertical polarization energy applications in which shocks, due to rough handling, may occur. As indicated in FIG. 12, coupler 50d comprises a distribution manifold 101 supported in contact with conducting cylinder 51. An input coaxial connector 102 is attached to a remote transverse end of the manifold 101. A series of output couplers 103, 104, 105 and 106 are connected at axially spaced locations along the length of the manifold 101. As indicated in FIG. 12, the couplers 103, 104, 105 and 106 have bases attached to central cylinder 51, and radially directed extensions connect to the adjacent ends of the pairs of helical conductors 52, 53 and 54, 55. Preferably these parts are connected at two sets of selected coupling points about the central cylinder 51 indicated at 107, 108 and at 109, 110. Each set of points 107, 108 or 109, 110 is azimuthally spaced so that it is aligned along a line 111 or 112 parallel to the longitudinal axis of the central cylinder 51. The lines 111 and 112 are also diametrically opposed. Where the turn circumferential length of the helical conductors 52, 53 and 54, 55 is equal to an integral full operating wavelength, the spacing between the coupling points 107, 108 or 109, 110 is equal to one-half circumferential turn length or its integral equivalent, measured along the longer of each pair of helical conductors beginning at the center of the antenna, as previously explained.

Essentially, manifold 101 is electrically equivalent to the coupler 50c of FIG. 11. Energy is fed from the input transmission line 82' to input coupler 102 then through the manifold 101 to the center of the antenna between the pairs of helical conductors 52, 53 and 54, 55 and to cylindrical conductor 51. Within the manifold 101, the input signal currents are divided, as explained below. Voltages are developed between the pairs of helical conductors and the central cylinder by connecting the outer conductor of the input line 82' to the central cylinder 51 through the coupler 102 at the end of the manifold 101. The coupler 102 in turn connects to the central cylinder 51 through the sidewall of the manifold 101 in surface contact with the central cylinder 51.

Manifold 101 need not be unitarily formed. As indicated in FIG. 13, the manifold 101 may be laminated, comprising a plurality of conducting plates 115, 116, 117 and 118 having a plurality of broad surfaces parallel to the longitudinal axis of symmetry of the manifold. Across the broad surfaces of the plates are provided a series of concavities 119, 120, 121, 122 and 123 progressing from a single input concavity 119 to a series of output concavities 120, 121, 122 and 123. The concavities are constructed so that, as the plates 115, 116, 117 and 118 are stacked in horizontal mating contact along the adjacent broad surfaces, they are adapted to mate to form grooves of circular cross section.

Within the mated concavities 119, 120, 121, 122 and 123 is assembled a split, similarly oriented, inner conductor section 125 of FIG. 14. The conductor section 125 is shown removed from contact with plates 115, 116, 117 and 118. As indicated, section 125 is split into a series of segments 131, 132, 133, 134, 135, 136 and 137 connectable to respective extensions 138 of output posts 103, 104, 105 and 106. The posts are indicated as being connected to the central cylinder by nuts 139.

Along the section 125 are a series of wafers 140 of circular cross section located within the mated concavities of the manifold having a central opening through which a segment of the inner conductor section 125 extends. The wafers 140 are formed of electrically insulating material.

When the inner conductor section 125 is supported between the plates 115, 116, 117 and 118, the minimum radial spacing between the inner conductor section and the sidewall of the plates is determined by the dielectric strength of the medium carrying the electromagnetic waves. For air-dielectric transmission lines, the maximum potential gradient at sea level pressure is about 30,000 volts per centimeter. Where the radial spacing between the parts becomes limited, as across segments 131, 132 and 133 where the wafers 140 are of smaller diameter, it is desirable to further reduce the radial spacing below the normal breakdown gradient of the air-dielectric transmitting medium. In such applications, arcing may be avoided by introducing a gas, such as nitrogen (dielectric constant = 1), within the manifold 101 at a pressure greater than that of the atmosphere, say 300 p.s.i. The maximum power that can be transmitted by the manifold coupler is thereby increased to that having at least a tested breakdown potential gradient of say 100,000 volts per cm.

In operation, signal currents are coupled by the input segment 131 of the inner conductor section 125 (FIG. 14) to a plane near the midpoint of the manifold where the currents then divide at output segments 134, 135, 136 and 137 for ultimate connection to coupling posts 105, 106, 107 and 108. As indicated in FIG. 15, segments 132 and 133 may have ends arcuately formed changing the relative elevations of the output segments 134, 135, 136 and 137 to further aid in forming an

antenna of minimum diameter. Furthermore, to facilitate matching of the system, the segments 132, 133, 134, 135, 136 and 137 preferably have different impedance values so that the input line 82' (FIG. 12) may be formed of a commonly available transmission line.

While certain preferred embodiments of the invention have been specifically disclosed, it should be understood that the invention is not limited thereto as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims. For example, the pairs of electromagnetic waves propagating in opposed axial directions away from the midpoint of the antenna may be controlled by suitable phase controllers to interact to radiate circularly polarized electromagnetic energy into the adjacent earth formation.

We claim:

1. A method of forming a high-gain helical antenna for irradiating an earth formation penetrated by a borehole to approximate the distance to an electromagnetic discontinuity in said formation from said borehole, comprising the steps of:

a. forming a two-wire electromagnetic coupling means having a single input terminal connectable to a source of electromagnetic energy, and a plurality of radially directed output terminals terminating exterior of and axially spaced along the midportion of an axially elongated central cylindrical conducting element of an electrically conductive material, by the substeps of:
   forming a plurality of axially elongated plates of an electrically conductive material having broad surfaces;
   grooving adjacent broad surfaces thereof to form a distribution pattern including a single input groove and a plurality of output grooves;
   locating a single-wire conductor within the grooves having a single input end and a plurality of remote output ends;
   stacking the plates into a unitary assembly;
   attaching a two-wire transmission line to said assembled plates, one wire of said transmission line connected to said wire conductor within said grooves, the other wire of said transmission line being connected to said plates;
   inserting the assembled plates within and in contact with the central cylindrical element whereby said plurality of remote near ends of said single-wire conductor within said grooves are alignable with openings in said central element so as to terminably contact said plurality of output terminals exterior of said control element;

b. forming first and second pairs of helical conducting elements of an electrically conductive material about said central conducting element, each of said pairs of helical conducting elements adapted to helically wind about said central conducting element in the same circumferential direction having near ends at said midportion of said cylindrical conducting element and remote ends terminating at a remote end of said cylindrical conducting element;

c. spacing each helical conducting element in an axial direction along said central cylindrical element, so that each turn is adapted to have a common circumferential length equal to an integral operating wavelength of the electromagnetic energy in said formation; and

d. connecting the plurality of output terminals of said near ends of the first and second pairs of helical conducting elements so as to shorten one of said helical conductors of each pair of helical conducting elements a circumferential distance relative to said other helical conductor of each pair of helical conductors, said distance being about a half of one integral turn of said helical conductors, and thereby enable the production of first and second pairs of electromagnetic waves propagating in opposed axial directions from said coupling means.

2. The method as in claim 1 with the additional step of pressurizing the dielectric medium of said coupling means located between said single-wire conductor and said plates so as to increase the breakdown gradient therebetween, said dielectric medium having a dielectric constant equal to about one.

3. The method as in claim 2 in which the dielectric pressurizing medium is an inert gas at a pressure greater than 15 p.s.i.

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(54) ANTENNA

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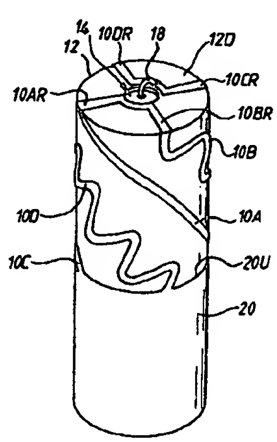
(57) **ABSTRACT**

An antenna for use at UHF and upwards has a cylindrical ceramic core with a relative dielectric constant of at least 5. A three-dimensional radiating element structure, consisting of helical antenna elements on the cylindrical surface of the core and connecting radial elements on a distal end face of the core, is formed by conductor tracks plated directly on the core surfaces. At the distal end face the elements are connected to an axially located feed structure in a plated axial passage of the core. The antenna elements are grounded on a plated sleeve covering a proximal part of the core which, in conjunction with the feeder structure, forms an integral balun for matching to an unbalanced feeder.

55 Claims, 2 Drawing Sheets



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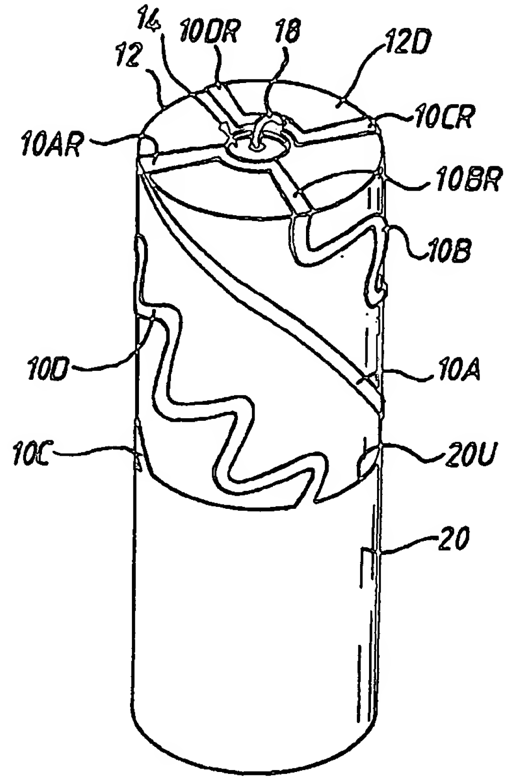
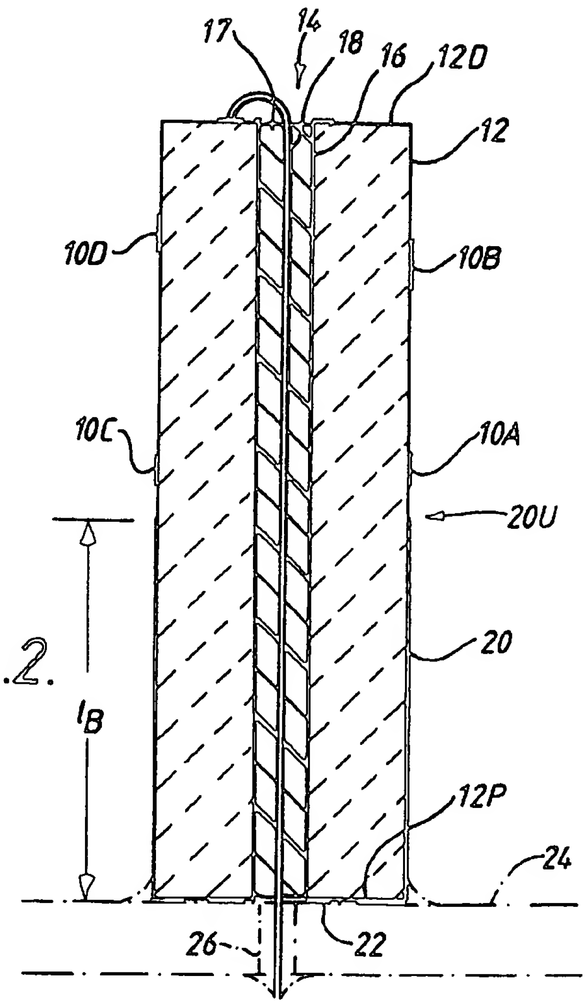


14
12
10DR
18
12D
10AR
10CR
10BR
10B
10D
10A
10C
20U
20

Fig.1.



17
14
18
16
12D
12
10D
10B
10C
10A
20U
20
l_B
12P
24
26
22

Fig.2.

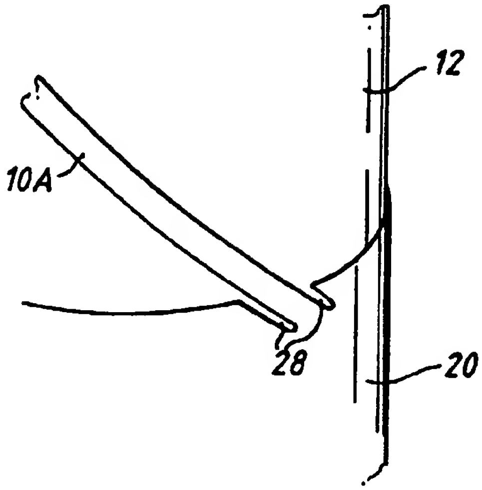


Fig.3.

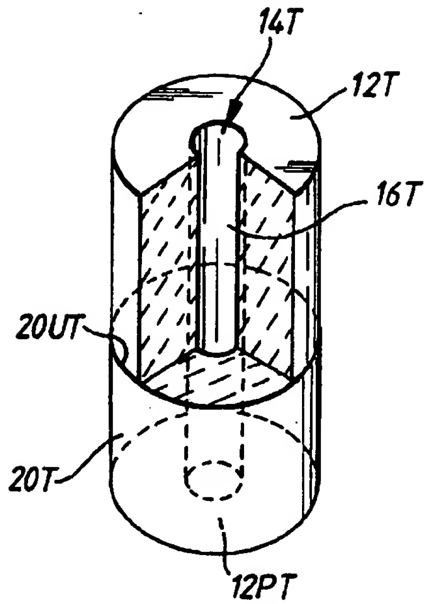


Fig.4.

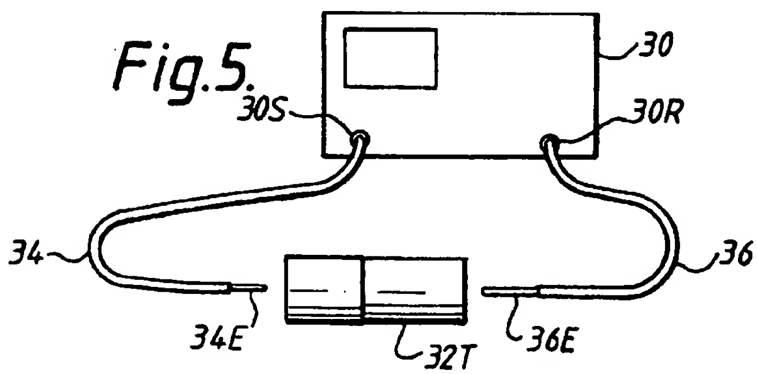


Fig.5.

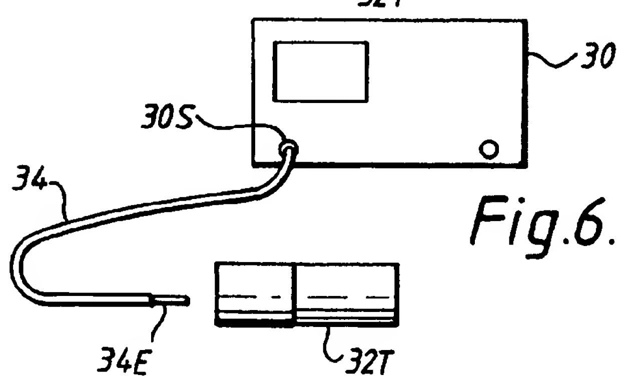


Fig.6.

ANTENNA

CONTINUING APPLICATION DATA

This application is a continuation of application entitled *An Antenna* invented by Oliver Paul Leisten and having application Ser. No. 08/351,631, filed on Dec. 6, 1994 now U.S. Pat. No. 5,854,608, and which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

This invention relates to an antenna for operation at frequencies in excess of 200 MHz, and in particular to an antenna which has a three-dimensional antenna element structure.

BACKGROUND OF THE INVENTION

British Patent No. 2258776 discloses an antenna which has a three-dimensional antenna element structure by virtue of having a plurality of helical elements arranged around a common axis. Such an antenna is particularly useful for receiving signals from satellites, for example, in a GPS (global positioning system) receiver arrangement. The antenna is capable of receiving circularly polarised signals from sources which may be directly above the antenna, i.e. on its axis, or at a location a few degrees above a plane perpendicular to the antenna axis and passing through the antenna, or from sources located anywhere in the solid angle between these extremes.

While being intended mainly for reception of circularly polarised signals, such an antenna, due to its three-dimensional structure, is also suitable as an omnidirectional antenna for receiving vertically and horizontally polarised signals.

One of the disadvantages of such an antenna is that in certain applications it is insufficiently robust, and cannot easily be modified to overcome this difficulty without a performance penalty. For this reason, antennas which are to receive signals from the sky in harsh environments, such as on the outside of an aircraft fuselage, are often patch antennas, being simply plates (generally plated metallic square patches) of conductive material mounted flush on an insulated surface which may be part of the aircraft fuselage. However, patch antennas tend to have poor gain at low angles of elevation. Efforts to overcome this disadvantage have included using a plurality of differently oriented patch antennas feeding a single receiver. This technique is expensive, not only due to the numbers of elements required, but also due to the difficulty of combining the received signals.

SUMMARY OF THE INVENTION

According to one aspect of this invention an antenna for operation at a frequency in excess of 200 MHz comprises an electrically insulative antenna core of a material having a relative dielectric constant greater than 5, a three-dimensional antenna element structure disposed on or adjacent the outer surface of the core and defining an interior space, and a feeder structure which is connected to the element structure and passes through the core, the material of the core occupying the major part of the said interior space.

Typically the element structure comprises a plurality of antenna elements defining an envelope centred on a feeder structure which lies on a central longitudinal axis. The core is preferably a cylinder and the antenna elements preferably define a cylindrical envelope which is coaxial with the core. The core may be a cylindrical body which is solid with the exception of a narrow axial passage housing the feeder. Preferably, the volume of the solid material of the core is at least 50 percent of the internal volume of the envelope defined by the elements, with the elements lying on an outer cylindrical surface of the core. The elements may comprise metallic conductor tracks bonded to the core outer surface, for example by deposition or by etching of a previously applied metallic coating.

For reasons of physical and electrical stability, the material of the core may be ceramic, e.g. a microwave ceramic material such as zirconium-titanate-based material, magnesium calcium titanate, barium zirconium tantalate, and barium neodymium titanate, or a combination of these. The preferred relative dielectric constant is upwards of 10 or, indeed, 20, with a figure of 36 being attainable using zirconium-titanate-based material. Such materials have negligible dielectric loss to the extent that the Q of the antenna is governed more by the electrical resistance of the antenna elements than core loss.

A particularly preferred embodiment of the invention has a cylindrical core of solid material with an axial extent at least as great as its outer diameter, and with the diametrical extent of the solid material being at least 50 percent of the outer diameter. Thus, the core may be in the form of a tube having a comparatively narrow axial passage of a diameter at most half the overall diameter of the core. The inner passage may have a conductive lining which forms part of the feeder structure or a screen for the feeder structure, thereby closely defining the radial spacing between the feeder structure and the antenna elements. This helps to achieve good repeatability in manufacture. This preferred embodiment has a plurality of generally helical antenna elements formed as metallic tracks on the outer surface of the core which are generally co-extensive in the axial direction. Each element is connected to the feeder structure at one of its ends and to a ground or virtual ground conductor at its other end, the connections to the feeder structure being made with generally radial conductive elements, and the ground conductor being common to all of the helical elements.

According to another aspect of the invention, an antenna for operation at a frequency in excess of 200 MHz comprises a solid electrically insulative antenna core which has a central longitudinal axis and is made of a material having a relative dielectric constant greater than 5, a feeder structure extending through the core on the central axis, and, disposed on the outer surface of the core, a radiating element structure comprising a plurality of antenna elements which are connected to the feeder structure at one end of the core and extend in the direction of the opposite end of the core to a common grounding conductor. The core preferably has a constant external cross-section in the axial direction, with the antenna elements being conductors plated on the surface of the core. The antenna elements may comprise a plurality of conductor elements extending longitudinally over the portion of the core having a constant external cross-section, and a plurality of radial conductor elements connecting the longitudinally extending elements to the feeder structure at the said one end of the core. The phrase "radiating element structure" is used in the sense understood by those skilled in the art, that is to mean elements which do not necessarily radiate energy as they would when connected to a transmitter, and to mean, therefore, elements which either collect or radiate electromagnetic radiation energy. Accordingly the antenna devices which are the subject of this

specification may be used in apparatus which only receives signals, as well as in apparatus which both transmits and receives signals.

In a particularly preferred embodiment of the invention, the antenna includes an integral balun formed by a conductive sleeve extending over part of the length of the core from a connection with the feeder structure at the above-mentioned opposite end of the core. The balun sleeve may thus also form the common grounding conductor for the longitudinally extending conductor elements. In the case of the feeder structure comprising a coaxial line having an inner conductor and an outer screen conductor, the conductive sleeve of the balun is connected at the said opposite end of the core to the feeder structure outer screen conductor.

The preferred embodiment of the antenna, having a core which is a solid cylinder, includes an antenna element structure comprising at least four longitudinally extending elements on the cylindrical outer surface of the core and corresponding radial elements on a distal end face of the core connecting the longitudinally extending elements to the conductors of the feeder structure. Preferably, these longitudinally extending antenna elements are of different lengths. In particular, in the case of an antenna having four longitudinally extending elements, two of the elements are of greater length than the other two by virtue of following meandered paths on the outer surface of the core. In the case of an antenna for circularly polarised signals, all four elements follow a generally helical path, the longer of the two elements each following a meandering course which deviates, preferably, sinusoidally on each side of a helical centre line. The conductor elements connecting the longitudinally extending elements to the feeder structure at the distal end of the core are preferably simple radial tracks which may be inwardly tapered.

Using the above-described features it is possible to make an antenna which is extremely robust due to its small size and due to the elements being supported on a solid core of rigid material. Such an antenna can be arranged to have the same low-horizon omni-directional response as the prior art antenna which is mainly air-cored, but with robustness sufficient for use as a replacement for patch antennas in certain applications. Its small size and robustness render it suitable also for unobtrusive vehicle mounting and for use in handheld devices. It is possible in some circumstances even to mount it directly on a printed circuit board. Since the antenna is suitable for receiving not only circularly polarised signals, but also vertically or horizontally polarised signals, it may be used not only in satellite navigation receivers but also in different types of radio communication apparatus such as handheld mobile telephones, an application to which it is particularly suited in view of the unpredictable nature of the received signals, both in terms of the direction from which they are received, and the polarisation changes brought about through reflection.

Expressed in terms of operating wavelength in air λ, the longitudinal extent of the antenna elements, i.e. in the axial direction, is typically within the range of from 0.031λ to 0.061λ, and the core diameter is typically 0.02λ to 0.03λ. The track width of the elements is typically 0.0015λ to 0.0025λ, while the deviation of the meandered tracks from a helical mean path is 0.0035λ to 0.0065λ on each side of the mean path, measured to the centre of the meandered track. The length of the balun sleeve is typically in the range of from 0.03λ to 0.06λ.

According a third aspect of the invention, there is provided an antenna for operation at a frequency in excess of 200 MHz, wherein the antenna comprises an antenna element structure in the form of at least two pairs of helical elements formed as helices having a common central axis, a substantially axially located feeder structure having an inner feed conductor and an outer screen conductor with each helical element having one end coupled to a distal end of the feeder structure and its other end connected to a common grounding conductor, and a balun comprising a conductive sleeve located coaxially around the feeder structure, the sleeve being spaced from the outer screen of the feeder structure by a coaxial layer of insulative material having a relative dielectric constant greater than 5, with the proximal end of the sleeve connected to the feeder structure outer screen. Preferably, the axial length of the helical elements is greater than the length of the sleeve of the balun. The sleeve conductor of the balun may also form the common grounding conductor, with each helical element terminating at a distal edge of the sleeve. In an alternative embodiment, the distal edge of the sleeve is open circuit, and the common grounding conductor is the outer screen of the feeder structure.

The invention also includes, from another aspect, a method of manufacturing an antenna as described above, comprising forming the antenna core from the dielectric material, and metallising the external surfaces of the core according to a predetermined pattern. Such metallisation may include coating external surfaces of the core with a metallic material and then removing portions of the coating to leave the predetermined pattern, or alternatively a mask may be formed containing a negative of the predetermined pattern, and the metallic material is then deposited on the external surfaces of the core while using the mask to mask portions of the core so that the metallic material is applied according to the pattern.

A particularly advantageous method of producing an antenna having a balun sleeve and a plurality of antenna elements forming part of a radiating element structure, comprises the steps of providing a batch of the dielectric material, making from the batch at least one test antenna core, and then forming a balun structure, preferably without any radiating element structure, by metallising on the core a balun sleeve having a predetermined nominal dimension which affects the frequency of resonance of the balun structure. The resonant frequency of this test resonator is then measured and the measured frequency is used to derive an adjusted value of the balun sleeve dimension for obtaining a required balun structure resonant frequency. The same measured frequency can be used to derive at least one dimension for the antenna elements of the radiating element structure to give a required antenna elements frequency characteristic. Antennas manufactured from the same batch of material are then produced with a balun sleeve and antenna elements having the derived dimensions.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a perspective view of an antenna in accordance with the invention;

FIG. 2 is a diagrammatic axial cross-section of the antenna;

FIG. 3 is a fragmentary perspective view of part of the antenna;

FIG. 4 is a cut-away perspective view of a test resonator;

FIG. 5 is a diagram of a test rig including the resonator of FIG. 4; and

FIG. 6 is a diagram of an alternative test rig.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, a quadrifilar antenna in accordance with the invention has an antenna element structure with four longitudinally extending antenna elements **10A**, **10B**, **10C**, and **10D** formed as metallic conductor tracks on the cylindrical outer surface of a ceramic core **12**. The core has an axial passage **14** with an inner metallic lining **16**, and the passage houses an axial feeder conductor **18**. The inner conductor **18** and the lining **16** in this case form a feeder structure for connecting a feed line to the antenna elements **10A–10D**. The antenna element structure also includes corresponding radial antenna elements **10AR**, **10BR**, **10CR**, **10DR** formed as metallic tracks on a distal end face **12D** of the core **12** connecting ends of the respective longitudinally extending elements **10A–10D** to the feeder structure. The other ends of the antenna elements **10A–10D** are connected to a common grounding conductor **20** in the form of a plated sleeve surrounding a proximal end portion of the core **12**. This sleeve **20** is in turn connected to the lining **16** of the axial passage **14** by plating **22** on the proximal end face **12P** of the core **12**.

As will be seen from FIG. **1**, the four longitudinally extending elements **10A–10D** are of different lengths, two of the elements **10B**, **10D** being longer than the other two **10A**, **10C** by virtue of following a meandering course. In this embodiment, intended for circularly polarised signals, the shorter longitudinally extending elements **10A**, **10C** are simple helices, each executing a half turn around the axis of the core **12**. On the other hand, the longer elements **10B**, **10D** each follow a respective meandering course which is sinusoidal in shape, deviating on either side of a helical centre line. Each pair of longitudinally extending and corresponding radial elements (for example **10A**, **10AR**) constitutes a conductor having a predetermined electrical length. In the present embodiment, it is arranged that the total length of each of the element pairs **10A**, **10AR**; **10C**, **10CR** having the shorter length corresponds to a transmission delay of approximately 135° at the operating wavelength, whereas each of the element pairs **10B**, **10BR**; **10D**, **10DR** produce a longer delay, corresponding to substantially 225°. Thus, the average transmission delay is 180°, equivalent to an electrical length of $\lambda/2$ at the operating wavelength. The differing lengths produce the required phase shift conditions for a quadrifilar helix antenna for circularly polarised signals specified in Kilgus, "Resonant Quadrifilar Helix Design", The Microwave Journal, December 1970, pages 49–54. Two of the element pairs **10C**, **10CR**; **10D**, **10DR** (i.e. one long element pair and one short element pair) are connected at the inner ends of the radial elements **10CR**, **10DR** to the inner conductor **18** of the feeder structure at the distal end of the core **12**, while the radial elements of the other two element pairs **10A**, **10AR**; **10B**, **10BR** are connected to the feeder screen formed by metallic lining **16**. At the distal end of the feeder structure, the signals present on the inner conductor **18** and the feeder screen **16** are approximately balanced so that the antenna elements are connected to an approximately balanced source or load, as will be explained below.

The effect of the meandering of the elements **10B**, **10D** is that propagation of a circularly polarised signal along the elements is slowed in the helical direction compared with the speed of propagation in the plain helices **10A**, **10C**. The sealing factor by which the path length is extended by the meandering can be estimated using the following equation:

$$\text{Path length factor} = \left[\int_0^{2n\pi} \frac{\phi}{\cos\{\tan^{-1}[an\cos(n\phi)]\}}\, d\phi\right] \Big/ 2\pi$$

where:

- ϕ is the distance along the centre line of the meandered track, expressed in radians;
- a is the amplitude of the meandered path, also in radians; and
- n is the number of cycles of meandering.

With the left handed sense of the helical paths of the longitudinally extending elements **10A–10D**, the antenna has its highest gain for right hand circularly polarised signals.

If the antenna is to be used instead for left hand circularly polarised signals, the direction of the helices is reversed and the pattern of connection of the radial elements is rotated through 90°. In the case of an antenna suitable for receiving both left hand and right hand circularly polarised signals, albeit with less gain, the longitudinally extending elements can be arranged to follow paths which are generally parallel to the axis. Such an antenna is also suitable for use with vertically and horizontally polarised signals.

In the preferred embodiment, the conductive sleeve **20** covers a proximal portion of the antenna core **12**, thereby surrounding the feeder structure **16**, **18**, with the material of the core **12** filling the whole of the space between the sleeve **20** and the metallic lining **16** of the axial passage **14**. The sleeve **20** forms a cylinder having an axial length l_B as show in FIG. **2** and is connected to the lining **16** by the plating **22** of the proximal end face **12P** of the core **12**. The combination of the sleeve **20** and plating **22** forms a balun so that signals in the transmission line formed by the feeder structure **16**, **18** are converted between an unbalanced state at the proximal end of the antenna to a balanced state at the axial position corresponding to the upper edge **20U** of the sleeve **20**. To achieve this effect, the length l_B is such that, in the presence of an underlying core material of relatively high relative dielectric constant, the balun has an electrical length of $\lambda/4$ at the operating frequency of the antenna. Since the remainder of the feeder structure **16**, **18**, i.e. distally of the upper edge **20U** of the sleeve **20**, is embedded in the core material **12** and, to a lesser extent, since the annular space surrounding the inner conductor **18** is filled with an insulating dielectric material **17** having a relative dielectric constant greater than that of air, the feeder structure distally of the sleeve **20** has a short electrical length. Consequently, signals at the distal end of the feeder structure **16**, **18** are at least approximately balanced.

The antenna has a main resonant frequency of 500 MHz or greater, the resonant frequency being determined by the effective electrical lengths of the antenna elements and, to a lesser degree, by their width. The lengths of the elements, for a given frequency of resonance, is also dependent on the relative dielectric constant of the core material, the dimensions of the antenna being substantially reduced with respect to an air-cored similarly constructed antenna.

The preferred material for the core **12** is zirconium-titanate-based material. This material has the above-mentioned relative dielectric constant of 36 and is noted also for its dimensional and electrical stability with varying temperature. Dielectric loss is negligible. The core may be produced by extrusion or pressing.

The antenna elements **10A–10D**, **10AR–10DR** are metallic conductor tracks bonded to the outer cylindrical and end surfaces of the core **12**, each track being of a width at least

four times its thickness over its operative length. The tracks may be formed by initially plating the surfaces of the core 12 with a metallic layer and then selectively etching away the layer to expose the core according to a pattern applied in a photographic layer similar to that used for etching printed circuit boards. Alternatively, the metallic material may be applied by selective deposition or by printing techniques. In all cases, the formation of the tracks as an integral layer on the outside of a dimensionally stable core leads to an antenna having dimensionally stable antenna elements.

With a core material having a substantially higher relative dielectric constant than that of air, e.g. ϵ_r=36, an antenna as described above for L-band GPS reception at 1575 MHz typically has a core diameter of about 5 mm and the longitudinally extending antenna elements 10A–10D have a longitudinal extent (i.e. parallel to the central axis) of about 8 mm. The width of the elements 10A–10D is about 0.3 mm and the meandered elements 10B, 10D deviate from a helical mean path by about 0.9 mm on each side of the mean path, measured to the centre of the meandered track. Typically, there are five complete sinusoidal cycles of meander in each element 10B, 10D to produce the required 90° phase difference between the longer and shorter of the elements 10A–10D. At 1575 MHz, the length of the balun sleeve 22 is typically in the region of 8 mm or less. Expressed in terms of the operating wavelength λ in air, these dimensions are, for the longitudinal (axial) extent of the elements 10A–10D: 0.042λ, for the core diameter: 0.026λ, for the balun sleeve: 0.042λ or less, for the track width: 0.002λ, and for the deviation of the meandered tracks: 0.005λ. Precise dimensions of the antenna elements 10A–10D can be determined in the design stage on a trial and error basis by undertaking eigenvalue delay measurements until the required phase difference is obtained.

In general, however, the longitudinal extent of elements 10A–10D is between 0.03λ and 0.06λ, the core diameter between 0.02λ to 0.03λ, the balun sleeve between 0.03λ to 0.06λ, the track width between 0.0015λ to 0.0025λ, and the deviation of the meandered tracks between 0.0035λ to 0.0065λ.

As a result of the very small size of the antenna, manufacturing tolerances may be such that the precision with which the resonant frequency of the antenna can be maintained is insufficient for certain applications. In these circumstances, adjustment of the resonant frequency can be brought about by removing plated metallic material from the core, e.g. by laser erosion of part of the balun sleeve 20 where it meets one or more of the antenna elements 10A–10D as shown in FIG. 3. Here, the sleeve 20 has been eroded to produce notches 28 on either side of the junction with the antenna element 10A to lengthen the element thereby reducing its resonant frequency.

A significant source of production variations in resonant frequency is the variability of the relative dielectric constant of the core material from batch to batch. In a preferred method of manufacturing the antenna described above, a small sample of test resonators is produced from each new batch of ceramic material, these sample resonators preferably each having an antenna core dimensioned to correspond to the nominal dimension of the core of the antenna and plated only with the balun, as shown in FIG. 4. Referring to FIG. 4, the test core 12T, in addition to having a plated balun sleeve 20T, also has a plated proximal face 12PT. The inner passageway 14T of the core 12T may be plated between the proximal face 12PT and the level of the upper edge 2OUT of the balun sleeve 12T or, as is shown in FIG. 4, it may be plated over its whole length with a metallic lining 16T. The external surfaces of the core 12T distally of the balun sleeve 20T are preferably left unplated.

The core 12T is pressed or extruded from the ceramic material batch to nominal dimensions, and the balun sleeve is plated with a nominal axial length. This structure forms a quarter-wave resonator, resonating at a wavelength λ corresponding approximately to four times the electrical length of the sleeve 20T when fed at the proximal end of the passage 14T where it meets the proximal end face 12PT of the core.

Next, the resonant frequency of the test resonator is measured. This can be performed as shown diagrammatically in FIG. 5 by taking a network analyzer 30 and coupling its swept frequency source 30S to the resonator, here shown by the reference numeral 32T, using, for example, a coaxial cable 34 with the outer screen removed over the length of a short end portion 34E. End portion 34E is inserted in the proximal end of the passage 14T (see FIG. 4) with the outer screen of cable 34 connected to the metallised layer 16T adjacent the proximal face 12PT of the core 12T, and with the inner conductor of the cable 34 lying approximately centrally in the passage 14T to provide capacitive coupling of the swept frequency source inside the passage 14T. Another cable 36, with its end portion 36E having the outer screen similarly cut back, is connected to the signal return 30R of the network analyzer 30 and is inserted in the distal end of the passage 14T of the core 12T. The network analyzer 30 is set to measure signal transmission between source 30S and return 30R and a characteristic discontinuity is observed at the quarter-wave resonant frequency. Alternatively, the network analyzer can be set to measure the reflected signal at the swept frequency source 30S using the single cable arrangement shown in FIG. 6. Again, a resonant frequency can be observed.

The actual frequency of resonance of the test resonator depends on the relative dielectric constant of the ceramic material forming the core 12T. An experimentally derived or calculated relationship between a dimension of the balun sleeve 20T, for example, its axial length, on the one hand and resonant frequency on the other hand, can be used to determine how that dimension should be altered for any given batch of ceramic material in order to achieve the required resonant frequency. Thus, the measured frequency can be used to calculate the required balun sleeve dimension for all antennas to be made from that batch.

This same measured frequency, obtained from the simple test resonator, can be used to adjust the dimensions of the radiating element structure of the antenna, in particular the axial length of the antenna elements 10A–10D plated on the cylindrical outer surface of the core distally of the sleeve 20 (using reference numerals from FIGS. 1 and 2). Such compensation for variations in relative dielectric constant from batch to batch may be achieved by adjusting the overall length of the core as a function of the resonant frequency obtained from the test resonator.

Using the above-described method, it may be possible, depending on the accuracy with which the frequency characteristics of the antenna are to be set, to dispense with the laser trimming process described above with reference to FIG. 3. Although it is possible to use a complete antenna as a test sample, the advantage of using a resonator as described above with reference to FIG. 4, i.e. without a radiating element structure, is that a simple resonance can be identified and measured in the absence of interfering resonances associated with the radiating structure.

The above-described balun arrangement of the antenna, being plated on the same core as the antenna elements, is formed simultaneously with the antenna elements, and being

integral with the remainder of the antenna, shares its robustness and electrical stability. Since it forms a plated external shell for the proximal portion of the core 12, it can be used for direct mounting of the antenna on a printed circuit board, as shown in FIG. 2. For example, if the antenna is to be end-mounted, the proximal end face 12P can be directly soldered to a ground plane on the upper face of a printed circuit board 24 (shown in chain lines in FIG. 2). With the inner feed conductor 18 passing directly through a plated hole 26 in the board for soldering to a conductor track on the lower surface. Since the conductor sleeve 20 is formed on a solid core of material having a high relative dielectric constant, the dimensions of the sleeve to achieve the required 90° phase shift are much smaller than those of an equivalent balun section in air. The sleeve 20 also has the effect of extending the ground up to the level of the upper edge 20U where it is used for grounding the antenna elements 10A–10D, without intervening connecting elements.

It is possible within the scope of the invention to use alternative balun and feeder structures. For example, the feeder structure may have associated with it a balun mounted at least partly externally of the antenna core 12. Thus, a balun can be effected by dividing a coaxial feeder cable into two coaxial transmission lines acting in parallel, one being longer than the other by an electrical length of $\lambda/2$, the other ends of these parallel-connected coaxial transmission lines having their inner conductors connected to a pair of inner conductors passing through the passageway 14 of the core 12 to be connected to respective pairs of the radial antenna elements 10AR, 10DR; 10BR, 10CR.

As another alternative, the antenna elements 10A–10D can be grounded directly to an annular conductor at the proximal edge of the cylindrical surface of the core 12, a balun being formed by an extension of the feeder structure having a coaxial cable formed into, for example, a spiral on the proximal end face 12P of the core, so that the cable spirals outwardly from the inner passage 14 of the core to meet the annular conductor at the outer edge of the end face 12P where the screen of the cable is connected to the annular conductor. The length of the cable between the inner passageway 14 of the core 12 and the connection to the annular ring is arranged to be $\lambda/4$ (electrical length) at the operating frequency.

All of these arrangements configure the antenna for circularly polarised signals. Such in antenna is also sensitive to both vertically and horizontally polarised signals, but unless the antenna is specifically intended for circularly polarised signals, the balun arrangement can be omitted. The antenna may be connected directly to a simple coaxial feeder, the inner conductor of the feeder being connected to all four radial antenna elements 10AR–10DR at the upper face of the core 12, and the coaxial feeder screen being coupled to all four longitudinally extending elements 10A–10D via radial conductors on the proximal face 12P of the core 12. Indeed, in less critical applications, the elements 10A–10D need not be helical in their configuration, but it is merely sufficient that the antenna element structure as a whole, comprising the elements and their connections to the feeder structure, should be a three-dimensional structure so as to be responsive to both vertically and horizontally polarised signals. It is possible, for example, to have an antenna element structure comprising two or more antenna elements each with an upper radial connecting portion as in the illustrated embodiment, but also with a similar lower radial connecting portion and with a straight portion connecting the radial portions, parallel to the central axis. Other configurations are possible. This simplified structure is particularly applicable for cellular mobile telephony. A notable advantage of the antenna for handheld mobile telephones is that the dielectric core largely avoids detuning when the antenna is brought close to the head of the user. This is in addition to the advantages of small size and robustness.

As for the feeder structure within the core 12, in some circumstances it may be convenient to use a pre-formed coaxial cable inserted inside the passage 14, with the cable emerging at the end of the core opposite to the radial elements 10AR to 10DR to make a connection with receiver circuitry, for example, in a manner other than by the direct connection to a printed circuit board described above with reference to FIG. 2. In this case the outer screen of the cable should be connected to the passage lining 16 at two, preferably more, spaced apart locations.

In most applications the antenna is enclosed in a protective envelope which is typically a thin plastics cover surrounding the antenna either with or without an intervening space.

What is claimed is:

1. A radio telephone for use at frequencies greater than 200 MHz including an antenna which comprises an electrically insulative core of a solid material having a relative dielectric constant greater than 5, and a three-dimensional antenna element structure disposed on or adjacent the outer surface of the core and defining an interior volume, the material of the core occupying the major part of the said interior volume.

2. A radio telephone according to claim 1, further comprising a feeder structure which is connected to the antenna element structure and passes through the core.

3. A radio telephone according to claim 1, wherein:

the core is cylindrical and has distal and proximal end faces,

the antenna includes an axial feeder structure and

the antenna element structure comprises at least two antenna elements extending from one end face in the direction of the other, and radial elements on at least the said one end face connecting the antenna elements to the feeder structure.

4. A radio telephone according to claim 1, wherein the material of the core is ceramic and has a relative dielectric constant greater than 10.

5. A radio telephone according to claim 1, having a feeder structure which passes through the core and is connected to the antenna element structure, wherein the core is solid with the exception of a central passage housing the feeder structure.

6. A radio telephone according to claim 5, wherein the core is cylindrical, and has an axial extent at least as greater as its diameter, and with the diametrical extent of the solid material being at least 50 percent of the said outer diameter.

7. A radio telephone according to claim 1, wherein the core has a central axis and said antenna element structure comprises a plurality of antenna elements which are generally co-extensive in the axial direction.

8. A radio telephone according to claim 1, wherein the core has a central axis and the antenna has a feeder structure extending through the core on the central axis, the antenna element structure comprising a plurality of antenna elements which are connected to the feeder structure at one end of the core and extend in the direction of the opposite end of the core to a common interconnecting conductor.

9. A radio telephone according to claim 8, wherein the common interconnecting conductor forms a grounding conductor for the antenna element.

10. A radio telephone according to claim 8, wherein the common interconnecting conductor is formed as a sleeve around a portion of the core.

11. A radio telephone according to claim 10, wherein the sleeve:

is formed on an outer surface of the core and encircles the feeder structure;

has a rim to which the said antenna elements are joined; and

is connected to the feeder structure at the said opposite end of the core.

12. A radio telephone according to claim 11, wherein the feeder structure has an inner conductor and a coaxial outer screen conductor, and wherein the sleeve is connected to the screen conductor.

13. A radio telephone according to claim 8, wherein the antenna elements comprise helical tracks, and the sleeve is cylindrical.

14. A radio telephone according to claim 1, for handheld use.

15. A radio telephone having an antenna the main resonant frequency of which is in excess of 500 MHz wherein the antenna comprises an electrically insulative antenna core of a material having a relative dielectric constant greater than 5, a three-dimensional antenna element structure disposed on or adjacent the outer surface of the core and defining an interior volume, and a feeder structure which is connected to the antenna element structure and passes through the core, the material of the core occupying the major part of the said interior volume.

16. A radio telephone according to claim 15, wherein the antenna element structure comprises a plurality of antenna elements defining an envelope centered on a central longitudinal axis of the antenna, and wherein the feeder structure is coincident with the said axis.

17. A radio telephone according to claim 16, wherein the core is a cylinder and the antenna elements define a cylindrical envelope which is coaxial with the core.

18. A radio telephone according to claim 16, wherein the core is cylindrical and is solid with the exception of an axial passage housing the feeder structure.

19. A radio telephone according to claim 18, wherein the volume of the solid material of the core is at least 50 percent of the internal volume of the envelope defined by the elements, with the elements lying on an outer cylindrical surface of the core.

20. A radio telephone according to claim 16, wherein the elements comprise metallic conductor tracks bonded to the core outer surface.

21. A radio telephone according to claim 15, wherein the material of the core is a ceramic.

22. A radio telephone according to claim 21, wherein the relative dielectric constant of the material is greater than 10.

23. A radio telephone according to claim 15, having a cylindrical core of solid material with an axial extent at least as great as its outer diameter, and with the diametrical extent of the solid material being at least 50 percent of the outer diameter.

24. A radio telephone according to claim 23, wherein the core is in the form of a tube having an axial passage of a diameter less than a half of its overall diameter, the inner passage having a conductive lining.

25. A radio telephone according to claim 23, wherein the antenna element structure comprises a plurality of generally helical elements formed as metallic tracks on the outer surface of the core which are generally co-extensive in the axial direction.

26. A radio telephone according to claim 25, wherein each helical element is connected to the feeder structure at one of its ends and to another of said helical elements at its other end.

27. A radio telephone according to claim 26, wherein the connections to the feeder structure are made with generally radial conductive elements, and each helical element is connected to a ground or virtual ground conductor which is common to all of the helical elements.

28. A radio telephone for operation at a frequency in excess of 200 MHz having an antenna which comprises a solid electrically insulative antenna core which has a central longitudinal axis and is made of a material having a relative dielectric constant greater than 5, a feeder structure extending through the core on the central axis, and, disposed on the outer surface of the core, a plurality of antenna elements which are connected to the feeder structure at one end of the core and extend in the direction of the opposite end of the core to a common interconnecting conductor.

29. A radio telephone according to claim 28, wherein at least a portion of the core has a constant external cross-section in the axial direction, with the antenna elements being conductors plated on the surface of said portion.

30. A radio telephone according to claim 29, wherein the antenna elements comprise a plurality of conductor elements extending longitudinally over the portion of the core having a constant external cross-section, and plurality of radial conductor elements connecting the longitudinally extending elements to the feeder structure at said one end of the core.

31. A radio telephone according to claim 28, wherein the antenna includes an integral balun formed by a conductive sleeve extending over part of the length of the core from a connection with the feeder structure at the said opposite end of the core.

32. A radio telephone according to claim 31, wherein the balun sleeve forms the common conductor for the longitudinally extending conductor elements, and wherein the feeder structure comprises a coaxial line having an inner conductor and an outer screen conductor, the conductive sleeve of the balun being connected at said opposite end of the core to the feeder structure outer screen conductor.

33. A radio telephone according to claim 28, wherein the core is solid and has a cylindrical outer surface, and wherein the antenna elements comprise at least four longitudinally extending elements on the cylindrical outer surface and corresponding radial elements on a distal end face of the core connecting the longitudinally extending elements to the conductors of the feeder structure.

34. A radio telephone according to claim 33, wherein the longitudinally extending elements are of different lengths.

35. A radio telephone according to claim 34, wherein the antenna elements comprise four longitudinally extending elements, two of which are of greater length than the other two by virtue of following meandered paths on the outer surface of the core.

36. A radio telephone according to claim 35, wherein each of the four longitudinally extending elements follow a respective generally helical path, the longer of the two elements each following a respective meandering course which deviates to either side of a helical center line.

37. A radio telephone according to claim 33, wherein the radial elements are simple radial tracks which are all the same length.

38. A telephone antenna comprising an electrically insulative core of a solid material having a relative dielectric constant greater than 5, and a three-dimensional antenna element structure disposed on or adjacent the outer surface

of the core and defining an interior space, the material of the core occupying the major part of said interior space.

39. An antenna for operation at frequencies in excess of 200 MHz, comprising an electrically insulative core of a solid material having a relative dielectric constant greater than 5, a three-dimensional antenna element structure disposed on or adjacent an outer surface of the core and defining an interior volume, and a feeder structure which passes through the core and provides an electrically balanced feed connection with the antenna element structure, the material of the core occupying the major part of said interior volume.

40. An antenna according to claim 39, including an integral balun.

41. An antenna according to claim 40, wherein the balun includes a conductive layer on said outer surface of the core.

42. An antenna according to claim 41, wherein said conductive layer comprises a conductive sleeve around part of the core, and wherein the, feeder structure comprises a coaxial combination of an inner conductor and an outer screen conductor, and wherein the sleeve is connected to said outer screen conductor.

43. An antenna according to claim 42, wherein the core has a central axis and wherein said antenna element structure comprises a plurality of axially co-extensive antenna elements which extend from said balanced feed connection to a rim of the sleeve.

44. An antenna according to claim 43, wherein the core is cylindrical and the antenna elements are helical.

45. An antenna according to claim 43, wherein at least a portion of the core is of constant cross-section, centered on said axis, and wherein said antenna elements are located on an outer surface of said portion.

46. An antenna for operation at a frequency in excess of 200 MHz comprising:

- an antenna core in the form of an electrically insulative dielectric body made of a solid material having a dielectric constant greater than 5, wherein the body has an axis of symmetry and an outer surface directed outwardly from said axis, said outer surface enclosing an interior volume at least 50 percent of which is occupied by said material,
- a plurality of conductive antenna elements on said outer surface,
- a feeder connection for connecting the antenna elements to a feeder,
- and an integral balun.

47. An antenna according to claim 46, including a coaxial feeder having an inner conductor and an outer screen, the feeder being surrounded by said dielectric body material, wherein the balun comprises a conductive layer on said outer surface spaced from said feeder by said material.

48. An antenna according to claim 47, wherein the conductive layer is formed as a sleeve around part of the core, and wherein the feeder is located on said axis and passes through the core from said feeder connection to a second said connection, at which second connection said outer screen is connected to said sleeve.

49. An antenna according to claim 48, wherein the sleeve has a rim spaced from said second connection and wherein the antenna elements extend in an electrically parallel connection from said feeder connection to said rim.

50. An antenna for operation at a frequency in excess of 200 MHz comprising:

- an antenna core in the form of an electrically insulative dielectric body made of a solid material having a dielectric constant greater than 5, wherein the body has an axis of symmetry and an outer surface directed outwardly from said axis, said outer surface enclosing an interior volume at least 50 percent of which is occupied by said material,
- a plurality of conductive antenna elements on said outer surface,
- a feed connection, and
- a conductive sleeve formed on said outer surface and forming a cavity surrounding part of said dielectric body.

51. An antenna according to claim 50, including a coaxial feeder having an inner conductor and an outer screen, the feeder being surrounded by said dielectric body material, wherein the sleeve comprises a conductive layer on said outer surface spaced from said feeder by said material.

52. An antenna according to claim 50, wherein said dielectric body is a solid cylinder having first and second end surfaces, wherein one of said end surfaces is covered by a layer of conductive material, and wherein said sleeve is connected to said layer to form a cavity which extends from said one end surface to a sleeve rim located on said body at a position intermediate said first and second ends.

53. An antenna according to claim 52, further comprising a feeder, said cavity being connected to the feeder.

54. An antenna according to claim 53, wherein the feeder is located on said axis and passes through the core from said feeder connection connecting the feeder to said antenna elements to a second connection, at which second connection said outer screen is connected to said conductive layer.

55. An antenna according to claim 50, including a feeder, wherein the sleeve has a rim and wherein the antenna elements extend in an electrically parallel manner from said rim to a connection with the feeder.

* * * * *

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United States Patent [19]

Ow et al.

[11] **Patent Number: 5,349,365**

[45] **Date of Patent: Sep. 20, 1994**

[54] **QUADRIFILAR HELIX ANTENNA**

[76] Inventors: **Steven G. Ow**, 1130 Coventry Dr., Thousand Oaks, Calif. 93065; **Peter J. Connolly**, 1461 Paul St., Simi Valley, Calif. 91360

[21] Appl. No.: **779,895**

[22] Filed: **Oct. 21, 1991**

[51] **Int. Cl.**[5] **H01Q 11/08; H01Q 1/36**

[52] **U.S. Cl.** **343/895**; 333/26; 343/859; 343/863

[58] **Field of Search** 343/895, 821, 850, 857, 343/859, 860, 862, 863; 333/26; H01Q 1/34–1/36, 11/04–11/10

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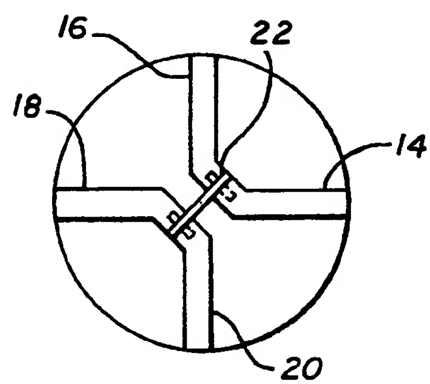
Primary Examiner—Rolf Hille
Assistant Examiner—Peter Toby Brown
Attorney, Agent, or Firm—Benman, Collins & Sawyer

[57] **ABSTRACT**

An improved helix antenna including a single unitary antenna having plural radiating elements extending radially from a common junction. A microstrip balun is connected to the plural antenna elements at the common junction. In a particular embodiment, the antenna includes four radiating elements arranged in a helical pattern and mounted such that a longitudinal axis extending through the axial center of the antenna is coincident with a longitudinal axis of the microstrip balun. One or more of the radiating elements includes a semicircular loop to create phase relationships necessary for a circularly polarized beam pattern. The microstrip balun includes a transmission line and a ground plane on opposite sides of a dielectric substrate. The transmission line and the ground plane are tapered for impedance matching between the input and the output thereof.

4 Claims, 3 Drawing Sheets



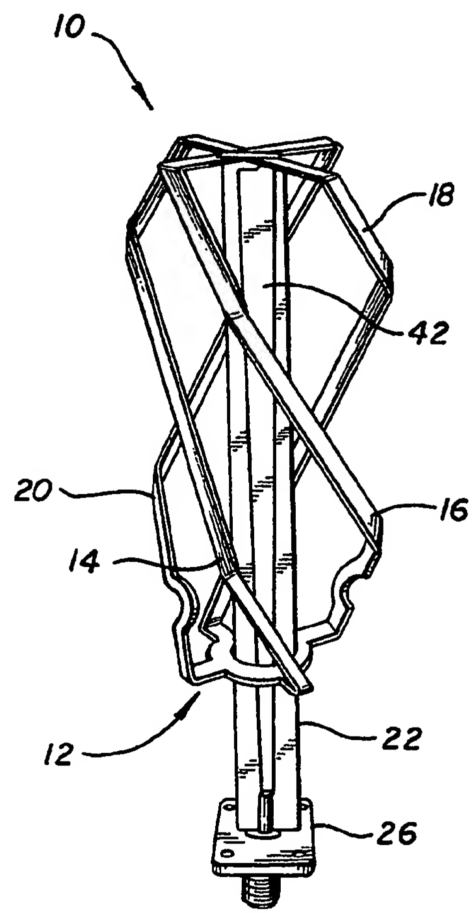


FIG. 1 PRIOR ART

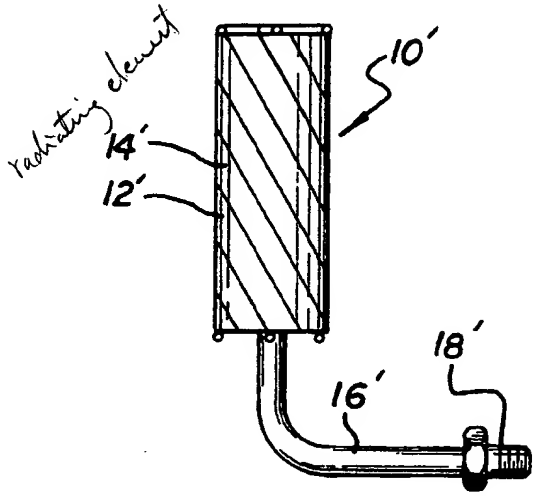
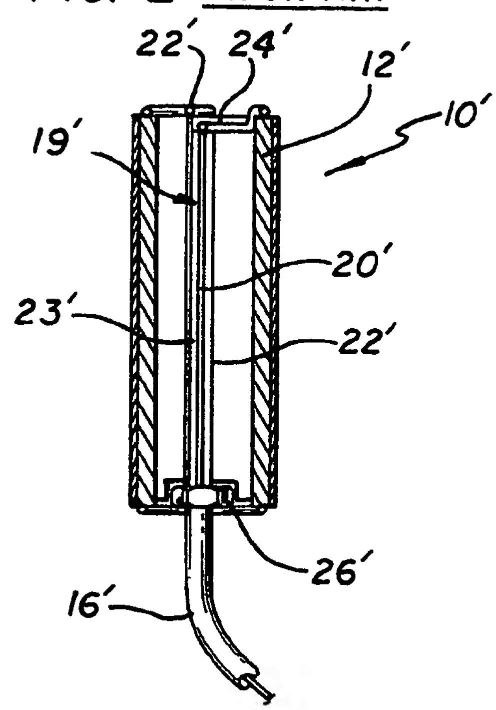


FIG. 2 PRIOR ART



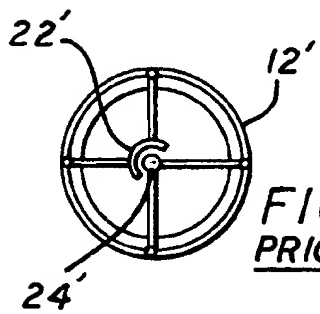


FIG. 3 PRIOR ART

FIG. 4

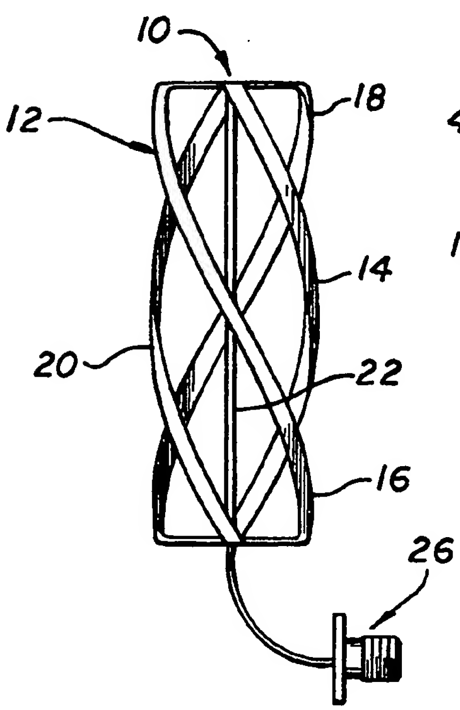


FIG. 5

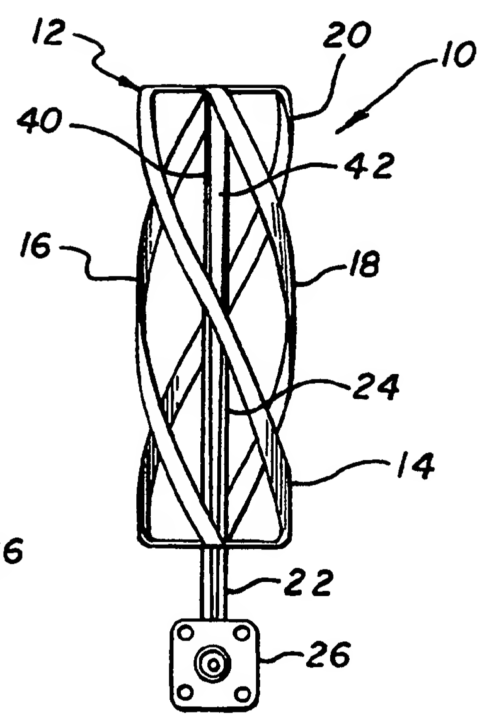


FIG. 6

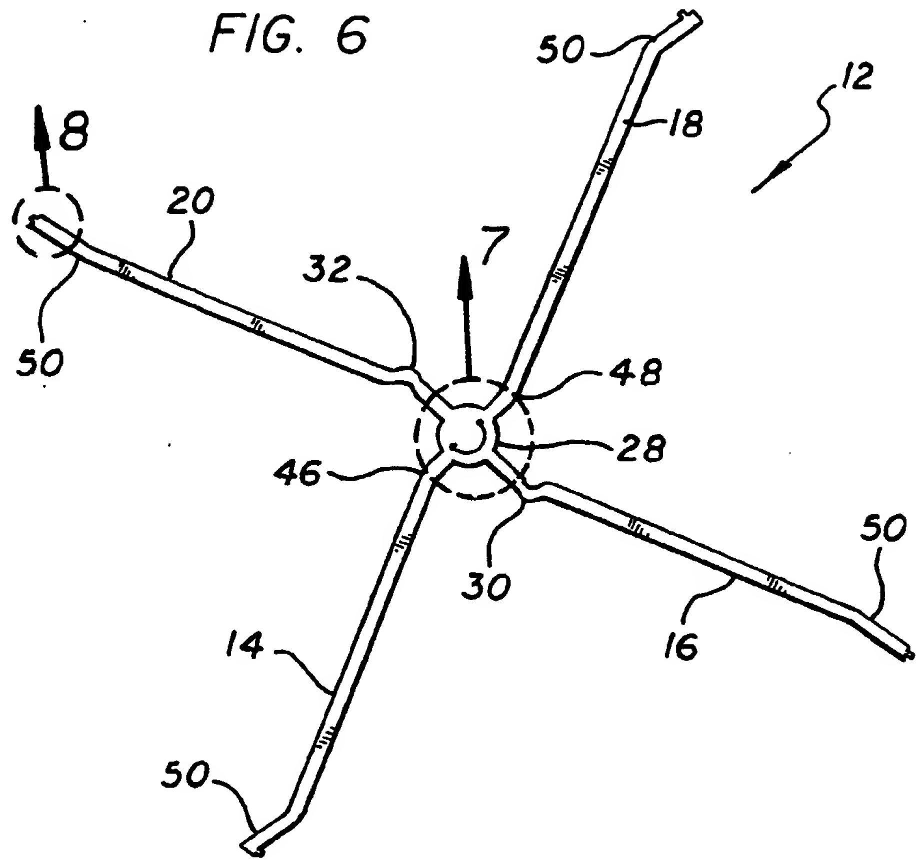
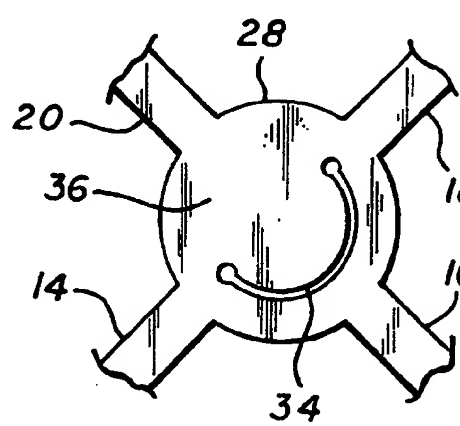


FIG. 7



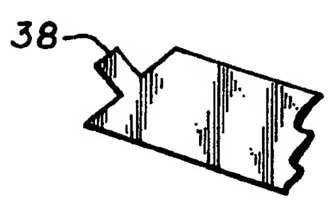


FIG. 8

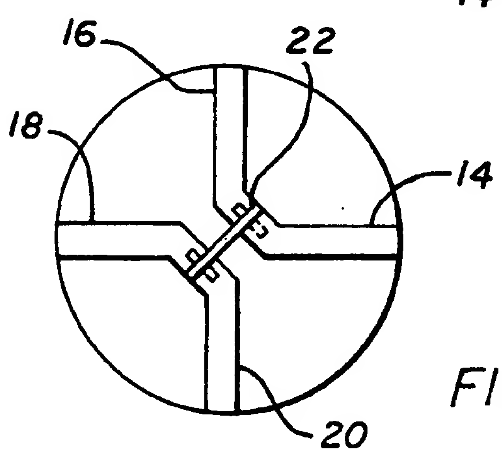


FIG. 9

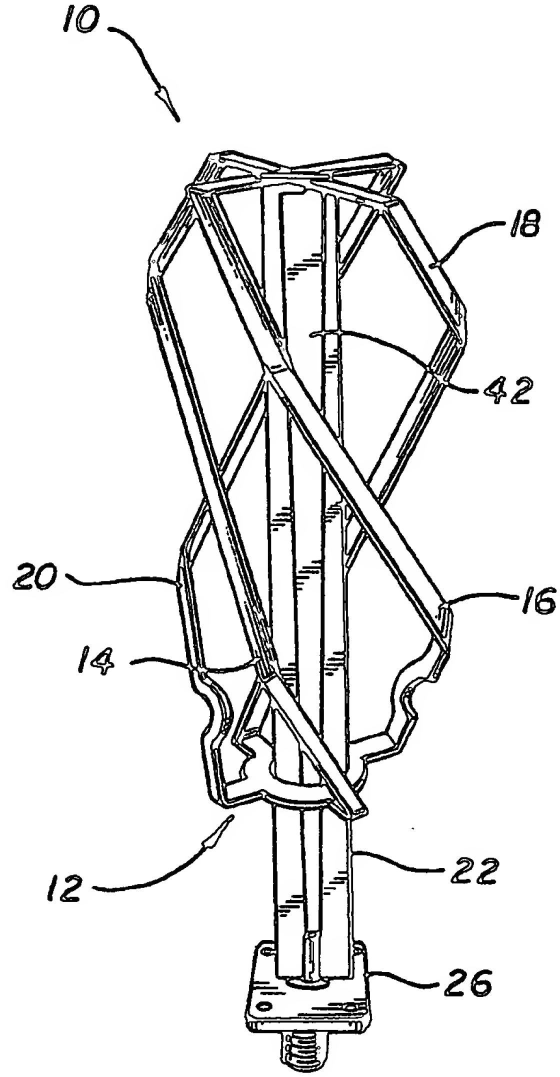


FIG. 10

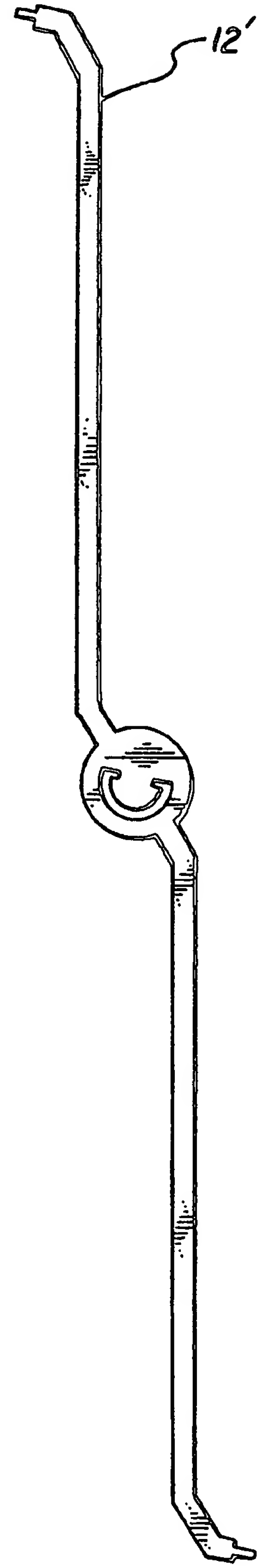


FIG. 11

QUADRIFILAR HELIX ANTENNA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to antennas. More specifically, the present invention relates to quadrifilar helix antennas.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

2. Description of the Related Art

The Global Positioning System (GPS) provides accurate position information in three dimensions (latitude, longitude, altitude). Position location is facilitated by a constellation of satellites. Each GPS satellite continuously transmits precise time and position data. GPS receivers read signals transmitted from three or more satellites and calculate the user's position based on the distance therefrom. In addition to position information, other navigation information may be calculated including, range, bearing to destination, speed and course over ground, velocity, estimated time of arrival and cross track error. The accuracy of the calculation is dependent on the quality of the signal detected from the satellite. Hence, the system requires a sufficiently accurate receiver and antenna arrangement. Specifically, the antenna must be small and portable with an omnidirectional beam pattern broad enough to detect signals from satellites located anywhere in the hemisphere. For this purpose, the quadrifilar helix antenna has been found to be well suited.

As discussed in Antenna Engineering Handbook, by Richard C. Johnson and Henry Jasik, pp. 13-19 through 13-21 (1984) a quadrifilar helix (or volute) antenna is a circularly polarized antenna having four orthogonal fractional-turn (one fourth to one turn) helixes excited in phase quadrature. Each helix is balun-fed at the top, and the helical arms are wires or metallic strips (typically four in number) of resonant length ($1=m\lambda/4$, $m=1, 2, 3, \ldots$) wound on a small diameter with a large pitch angle. This antenna is well suited for various applications requiring a wide hemispherical beam pattern over a relatively narrow frequency range.

In accordance with conventional wisdom, quadrifilar helix antennas are constructed of several pieces (e.g. 13) typically soldered by hand at numerous joints. The antennas are typically mass produced by unskilled labor. As a result, quadrifilar helix antennas constructed in accordance with conventional teachings are expensive to fabricate, nonrepeatable in design and therefore require hand tuning. In particular, conventional quadrifilar antennas have a coax feed which has a varied distance between the inside diameter and outside diameter to match the 50 ohm typical input impedance to 30 ohm typical feed output impedance for optimum power transfer into the antenna elements. This requires machining and hand assembly which complicates the design and increases the cost of construction.

Thus, there is a need in the art for a quadrifilar antenna design that allows for low construction and testing costs.

SUMMARY OF THE INVENTION

The need in the art is addressed by the improved helix antenna of the present invention. In a most general sense, the invention includes a single unitary antenna having plural radiating elements extending radially from a common junction. A microstrip balun/impedance transformer is connected to the plural antenna elements at the common junction. In a particular embodiment, the antenna includes four radiating elements arranged in a helical pattern and mounted such that a longitudinal axis extending through the axial center of the antenna is coincident with a longitudinal axis of the microstrip balun. Two of the radiating elements include delay lines (i.e., a semi-circular loop) to create phase relationships necessary for a circularly polarized beam pattern. The microstrip balun/impedance transformer includes a transmission line and a ground plane on opposite sides of a dielectric substrate. The transmission line and the ground plane are tapered for impedance matching between the input and the output thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front elevational view of a quadrifilar helix antenna constructed in accordance with conventional teachings.

FIG. 2 is a sectional view of a quadrifilar helix antenna constructed in accordance with conventional teachings.

FIG. 3 is a simplified top view of the quadrifilar helix antenna constructed in accordance with conventional teachings.

FIG. 4 is a side view of a quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 5 is a front view of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 6 is an isolated top view of the antenna element of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 7 is a detail view of the junction of the radiating element of FIG. 6.

FIG. 8 is a detail view of the end of a radiating element of the antenna element of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 9 is a detail view showing how the ends of the radiating elements of the antenna element of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 10 is a perspective view of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

FIG. 11 is an isolated top view of an alternative embodiment of the antenna element of the quadrifilar helix antenna constructed in accordance with the teachings of the present invention.

DESCRIPTION OF THE INVENTION

Illustrative embodiments and exemplary applications will now be described with reference to the accompanying drawings to disclose the advantageous teachings of the present invention.

FIG. 1 is a front elevational view of a quadrifilar helix antenna 10' constructed in accordance with conventional teachings. The antenna 10' includes a piece of printed circuit board 12' formed in a cylindrical shape, on which four radiating elements 14' are disposed by etching, deposition or other conventional process. The radiating elements 14' are fed at the top of the antenna 10' by a coaxial transmission line 16' from a coaxial connector 18'.

As illustrated in sectional view of FIG. 2, the coaxial transmission line is electrically connected to a balun/impedance transformer 20' which extends along the longitudinal axis of the board 12' to the top thereof at which an electrical connection is effected to each of the radiating elements 14'. The manner by which the connections are made is illustrated in the simplified top view of FIG. 3. Two of the radiating elements 14' (not shown) are soldered to the outer conductor 22' of the balun/impedance transformer 20' and the remaining two radiating elements (also not shown) are connected to the tapered center conductor 24' of the balun/impedance transformer 20'. This is illustrated in FIG. 2. The bottom ends of the radiating elements 14' are soldered to a machined ring 26' on the balun/impedance transformer 20'.

Thus, it is apparent that conventional quadrifilar helix antenna construction requires six solder connections at the top thereof, six at the bottom and two at the connector interface for a minimum of 14 solder connections.

As is well known in the art, the piecework and necessity for multiple solder connections requires costly hand work with labor equipped, at least, with soldering skills. In addition, the solder connections are characteristically nonrepeatable further requiring costly testing and retuning.

The quadrifilar antenna design of the present invention provides a simple low cost alternative conventional quadrifilar antenna designs. FIG. 4 is a side view and FIG. 5 is a front view of a quadrifilar helix antenna 10 constructed in accordance with the teachings of the present invention. The antenna 10 includes a unitary antenna element 12 and a microstrip balun/impedance transformer 22. The antenna element 12 is cut or stamped from a thin sheet of copper or other suitable conductor. In the illustrative embodiment, the antenna element 12 includes first, second, third and fourth radiating elements 14, 16, 18 and 20 respectively. FIG. 6 is a top view of the antenna element 12 showing the radiating elements 14, 16, 18 and 20 radially extending from a common junction 28. Note the loops 30 and 32 provided in the second and fourth radiating elements 16 and 20 respectively- The loops extend the length of the radiating element and thereby create a reactive component to feed the radiating arms in phase quadrature thereby producing circular polarization.

As illustrated in the detail view of FIG. 7, the common junction 28 is a radial hub within which a semi-circular slot 34 is cut. The slot 34 allows the tab 36 to be pushed up to provide an aperture and grounding solder/point for the microstrip balun/impedance transformer 22 to the antenna element. As illustrated in the detail view of FIG. 8, the free ends of the radiating elements include a tab 38. The edge of each radiating element serves to provide a landing 39. The landing 39 is significant because it self-indexes the element arms and maintains a constant phase differential between pairs of element arms. That is, when the tab 38 is fully inserted into the balun and seated against the landing 39, the landing phase delay is maintained. If there were no landing, the ends of the radiating elements would seat at various distances thereby changing the phase differential between element arms. As shown in the detail view of FIG. 9, the tabs 38 are fed through holes in the microstrip balun/impedance transformer 22 from opposing sides thereof, at which point the radiating elements are soldered to the microstrip balun/impedance transformer 22. These solder joints construct the antenna elements into a mechanically rigid structure.

Returning to FIG. 4, the antenna element 12 is fed by a microstrip balun/impedance transformer 22. The microstrip balun/impedance transformer is connected to a coax connector 26 on one end and to the antenna element 12 on the other. The microstrip balun/impedance transformer 22 is a thin strip of dielectric material 40 of teflon and fiberglass or other suitable material. The dielectric has a tapered transmission line 42 deposited on one side and a tapered ground plane 44 (not shown) deposited on the other.

The transmission line 42 is illustrated in the front view of FIG. 5. In the illustrative embodiment, the tapers of the transmission line 42 and the ground plane 44 are designed to provide a 50 ohm coax input impedance and a 30 ohm antenna output impedance for optimum power transfer.

FIG. 10 is a perspective view of the quadrifilar helix antenna 10 of the present invention.

In construction, the microstrip balun/impedance transformer 22 is inserted through the aperture in the junction 28 of the antenna element 12. The radiating elements are folded at the loops 30 and 32 and at the bends 46, 48 and 50 (FIG. 6) into the helical shape of FIGS. 4 and 5. The tabs 38 of the radiating elements extend through apertures in the dielectric 40 and the element self-index landing 39 accurately locates the element position as illustrated in FIG. 9. The transmission line 42 is shaped at the top of the dielectric 40 so that it may be solder connected to the tabs of two of the antenna radiating elements (e.g., 14 and 16) on one end thereof on one side of the dielectric 40. At the other end, the transmission line 42 is soldered to the center conductor of the coax connector 26 (See FIG. 10). The ground plane 44 is shaped at the top of the dielectric 40 so that it may be solder connected to the tabs of the remaining two antenna radiating elements (e.g., 18 and 20) on one end thereof.

At the other end, the ground plane 44 is connected to the outer conductor of the coax connector 26. Tab 36 of the antenna element 12, shown in FIG. 7, is soldered to the ground plane 44 of microstrip balun/impedance transformer 22. That is, the common junction 28 at the bottom of the antenna 10 is soldered to the ground plane 44 at the tab 36. The four free (distal) ends of the antenna elements are soldered at the top of the antenna to the balun/impedance transformer 22. Two adjacent arms 14 and 16 are soldered to the transmission line 42 and the other two elements 18 and 20 are soldered to the ground plane 44. Hence, only 5 solder connections are required.

FIG. 11 is an isolated top view of an alternative embodiment of the antenna element of the quadrifilar helix antenna 12' constructed in accordance with the teachings of the present invention. An antenna constructed in accordance with this design would employ two such antenna elements 12' to provide a complete antenna. The antenna 12' is otherwise constructed in the same manner as the antenna 12 of FIG. 6.

Thus, the present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications applications and embodiments within the scope thereof. For example, the invention is not limited to construction in a helical pattern. Nor is the invention limited to four radiating elements. Any number of radiating elements may be used within the scope of the present teachings.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

We claim:

1. An improved quadrifilar helix antenna comprising:

a unitary antenna having at least two radiating elements extending radially from a common junction and

a microstrip balun connected to said plural antenna elements at said common junction,

wherein said radiating elements are joined at distal ends thereof, arranged in a helical pattern, and mounted such that a longitudinal axis extending through the axial center of the antenna is coincident with a longitudinal axis of said microstrip balun and each of said antenna elements includes a tab at said distal end thereof adapted to engage a slot in said microstrip balun.

2. The invention of claim 1 wherein one or more of said antenna elements includes a semi-circular loop extending the length of said antenna element.

3. The invention of claim 1 wherein said balun includes a microstrip transmission line and a ground plane on opposite sides of a dielectric substrate.

4. The invention of claim 3 wherein said transmission line is tapered.

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